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ABSTRACT

This volume is an exposition of a mathematical modeling technique for use in the evaluation and solution of complex educational problems at all levels. It explores in detail the application of simple algebraic techniques to such issues as program reduction, fiscal rollbacks, and computer curriculum planning. Part I ("Introduction to the Modeling Formulation") discusses four stages of modeling development related to acceptance of a modeling formulation for decision-making, contextual assessment, planning for modeling development, and the specific design stage. These chapters use specific real-world problems to illustrate the purpose and application of the model. Part II ("Presentation of a Full Formulation"), also composed of four chapters, provides a detailed description of the multiple alternatives framework as a strategy for purchasing computer equipment. The chapters cover conceptualization, development of the framework, format for execution, and approaches to exploring results. Part III ("Example of a Complete Quantitative Solution") is a single chapter focusing on implementation of the model for determining fiscal rollbacks and program terminations during a crisis. Part IV consists of two chapters focusing on current extensions under research and development and a summary touching on related topics. Three appendixes provide a course outline and syllabus for Multiple Alternatives Analysis instruction and an outline for a field project proposal. (TE)

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No. 72

# MULTIPLE ALTERNATIVES FOR EDUCATIONAL EVALUATION AND DECISION-MAKING

BRENT EDWARD WHOLEBEN

University of Washington

May 1982

Nick L. Smith, Director
Research on Evaluation Program
Northwest Regional Educational Laboratory
300 S.W. Sixth Avenue, Portland, Oregon 97204

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# PREFACE

The Research on Evaluation Program is a Northwest Regional Educational Laboratory project of research, development, testing, and training designed to create new evaluation methodologies for use in education. This document is one of a series of papers and reports produced by program staff, visiting scholars, adjunct scholars, and project collaborators--all members of a cooperative network of colleagues working on the development of new methodologies.

How can mathematical modeling be used to assist in the solution of complex educational problems? What applications have been made of these techniques in applied settings? These and related issues are discussed at length in this volume on the use of multiple alternatives analysis in educational decision making. This volume discusses the nature and use of mathematical models, and how they are constructed and implemented in practical educational settings. An extensive example of the application of these procedures in determining fiscal cutbacks and program terminations during the reduction of educational funding is also provided here.

Nick L. Smith, Editor
Paper and Report Series

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# INTRODUCTION AND PROLOGUE

You are about to embark upon one of the more worthwhile reading exercises of your educational and administrative career.

This book contains an exposition of a mathematical technique for the evaluation and decision-making of some of the most complex issues facing professional educators today -- at all levels, from the building principal and district superintendent, to the state office superintendent and federal office director. The reader is advised and forewarned, that understanding the information found within this text will not proceed without conscious effort on the part of the individual wishing to understand the technique described within this text.

Considered (hopefully) a more readable and diversely applicable sequel to its predecessor:

> THE DESIGN, IMPLEMENTATION AND EVALUATION OF MATHEMATICAL MODELING PROCEDURES FOR DECISIONING AMONG EDUCATIONAL ALTERNATIVES (University Press of America, 1980; 474 pp.)

which dealt totally with the issue of decisioning school closures, this current text will explore in detail the application of simple algebraic techniques (commonly referred to as integer programming or operations research techniques) to such complex educational issues as program reduction, fiscal roll-backs, and the matching of computerized hardware/software purchases to existing curriculum objectives for computer-assisted and computer-managed instruction. Several other applications will also be mentioned in a later chapter devoted to current 'drawing-board' developmental designs.

The intent of this writing is of course to educate the reader as well as provide convincing evidence of the utility of the model illustrated for special evaluation and decision-making within what will be called the multiple alternatives context. In this context, potential solutions are viewed as multiple -- that is, the solution existing as a series of several individual actions which in combination effect the desired resolution of the identified problem. For example, the decision as to which school to close, and how many, are simultaneous, interactive-effects illustrations of the utility of the MAM framework. Equally important to the reader (as well as this author, obviously), is the fact that this book demonstrates the utility of quantitative assessment techniques for solving the more complex -- often said to be unsolvable -- problems facing the emerging educational professional today.

*Multiple Alternatives Analysis for Educational Evaluation and Decision-Making* is comprised of four major parts:

Part I: Introduction to the Modeling Formulation
Part II: Presentation of a Full Formulation
Part III: Example of a Complete Quantitative Solution
Part IV: Future Extensions and Summary

wherein each of the underlying eleven (11) chapters are presented as *stages* or *phases* of modeling development and construction.

The *first* part (Introduction to the Modeling Formulation) consists of four chapters which discuss the various stages of modeling development related to: acceptance of a modeling formulation for decision-making, contextual assessment, planning for modeling development, and lastly, its specific design. The specific content for these chapters will address the purpose of a modeling framework related to budgeting roll-backs under fiscal crises. The purpose of utilizing specific real-world problems to illustrate the application of the model is obvious.

The second part (Presentation of a Full Formulation) is composed of four chapters also; and provides a highly detailed, step-by-step narrative describing the multiple alternatives framework as a matching strategy for purchasing micro-computer hardware and software for CAI and CMI demands. These chapters provide information concerning: the initial conceptualization of the modeling framework, the development of its construction characteristics, the format for intended execution and implementation of the model, and lastly, the specific approach to be utilized in exploring the resulting solution(s).

Chapter Nine is the sole entrant within the third part of this manuscript, focusing specifically upon the actual implementation of a MAM framework for determining fiscal roll-backs and program terminations during a state of educational funding crisis. The reader is cautioned not to skip this chapter because of its technical nature, or since it is definitively mathematical. The presentation is written simply (or simply written, depending upon your point of view); and though requiring the reader to extend some effort, it is illustrative of the 'beauty' of the model for complex decision-making which effects the entire school district as a total organization.

Finally, the fourth part of this work consists of two chapters which focus upon current extensions under research and development, and some parting thoughts concerning the whole process, respectively. For the individual who intends to actually experiment with the approach narrated in this text, Chapter Eleven is must reading -- as of course (you realize) are the first ten chapters.

Good Reading!!

Brent E. Wholeben

# PART I

# INTRODUCTION TO THE MODELING FORMULATION

# CHAPTER 01

# INTRODUCTION TO THE MODELING FORMULATION

## [ Modeling as a Strategy for Evaluating Criterion-Referenced Multiple Alternatives ]

# INTRODUCTION TO CRITERION-REFERENCED MULTIPLE ALTERNATIVES MODELING

Educational decision-making has evolved into a most complex and demanding process. What was once a realm almost completely associated with experience and 'arm-chair reckoning', administrative perogative now demands a highly informed, structural and often equally complex approach to problem remediation. Educators and educational administrators in particular, have over the past several years chosen to ignore the need to develop more sophisticated decision-making strategies. Now however, the direction is clear. Problems representative of desegregation, declining enrollment, school closures, distinct consolidation, attendance boundary redistricting, P.L. 94-142 compliance and (education's perrenial nemesis) reduced funding allocation -- taunt every educational system, from small school districts through state and federal offices.

Many of today's complex educational issues can be translated into what has become known as the "multiple-alternatives problem" (Wholeben, 1980a). For example, in evaluating several elementary school sites for closure, the question is not, "whether site-A versus site-B is closed" but rather how many sites and which ones should be deactivated in order to fulfill: (1) the objectives of the required decision (what we will come to call 'constraints') and, (2) the needs of the district involved (which we will soon learn is the 'conditional vector'). Likewise in developing sophisticated curricular systems, the specialist discovers that many alternative instructional activities exist which could be implemented in fulfillment of the requirements for a priori stated instructional objectives (themselves related to desired concept-learning). Obvious resource factors such as time, cost and the varying expertise of available personnel militate against the otherwise optimal solution of "doing everything". However, the actual problem is much more subtle. For example, how related are activities 'A' and 'B' in regard to satisfying some aspect of objective A? Is A more costly yet more effective, while B is less costly but not as effective? Are both A and B similarly efficient in terms of time required for presentation and/or conclusion of the activity(s) itself? And even more subtle, does the selection of A in terms of some stated objective affect the activities that may be chosen for another objective, related to a different though required concept?

Thus, the multiple alternatives approach to modeling various complex situations in the educational sector is itself a complex milieu; with the purpose of designing a thorough, highly-structural decisioning model to adequately assist the educational decision-maker in understanding, analyzing and decisioning (sic) the multiple alternatives' problems faced today.

The treatise contained within this present volume concerns the expositon and multiple-alternatives interpretation of those complex and highly volatile problems in education, witnessed as:

> Given a situation of reduced resource allocation (and therefore required reduced expenditure) across educational units*, how many units will be continued and which ones; subject to the budget being balanced and the goals of the school (district) maximized ... while (of course) minimizing any perceivable negative impact upon the system as a whole.

*unit =: alternative program budgets for funding;
alternative school building sites for closure;
alternative curricular activites for implementation;
alternative matches for computer hardware and software for CAI/CMI instruction; and
alternative assignment patterns for attendance areas.

A final word (of caution) is required at this point for the reader.

Educational decision-making today is a tricky business, full of hidden agenda and unforeseen pitfalls. The responsible decision-maker views a complex issue as (therefore) complex; and does not subscribe to the overused adage, "simple solutions to complex problems should be your objective." Obviously, the problem solver cannot attach issues by "making mountains out of molehills", but must nonetheless recognize each "molehill" as a particulate-source of a "new mountain."

It is not the hidden goal of the author to convince the reader, that the multiple alternatives approach to certain educational problems is the perfect solution. However, the "MAM" is strongly suggested to be one of a minority of preferred techniques which the emerging educational administrator must be aware of and rudimentarily understand.

# VISIBILITY, RESPONSIBILITY AND ACCOUNTABILITY IN DECISIONING

Education is bombarded daily with demands for evaluative decision-making and clear-cut answers to those dilemmas currently facing the schools. Declining enrollments, schools closures, decreasing fiscal reserves and funding bases, personnel lay-offs, inability of high students to read, write and compute at desired proficiency standards, desegregation and bussing, inner-city flight and suburban blight, grade-level reconfigurations for redistributing certain age-segments of children for maximized program coverage, and fiscal program roll-backs and instructional program discontinuations -- all focus upon a very simple point that most educational administrators have failed to recognize throughout the past two decades:

> valid and reliable solutions to complex issues occur *if* *and* *only* *if* the evaluation and decision-making procedures to develop those solutions were themselves valid and reliable.

Although the reader might acknowledge the above rumination as a rather trite comment, it nevertheless can no longer be ignored, that education is ill-prepared to deal with many of the problems facing it today. Current problems associated with school closures or fiscal roll-backs are extremely *complex* (admittedly, also trite), yet administrators still cling to that age-old adage:

> "Don't make mountains out of mole hills!",

sharing in the belief that complex problems do not require complex evaluations and decision-making strategies. This is *not* a belief shared by this author, however.

## The Age of Complexity

With the advent of computerization -- and their wide-spread acceptance and utilization during the most recent decade -- the notion of complexity is no longer a barrier to informed decision-making within the educational sector. Even in terms of the simple and very affordable micro-computer (including APPLE and TRS-80), sophisticated evaluation and decision-oriented software packages are available and moreover highly usable, without a great deal of prior training or instruction (e.g. DB MASTER -- a management information system database generator; or VISICALC -- an arithmetic worksheet computational scheme for quantitatively-oriented analysis needs).

Whereas the issue of complexity was often a legitimate reason for not being able to solve complicated problems as recent as the early 1960's, it has today become a oft-used hedging-technique behind which unsophisticated and uninformed adminstrators attempt to hide from their responsibilities as educational leaders.

One only has to survey the various colleges and universities where educational administrators are trained and certified, to obtain an accurate picture of the reason for decay and retrenchment within education leadership today. Ability to understand and apply statistical analysis, research methods and evaluation procedures are viewed as academic course requirements -- rather than as knowledge and/or practitioner prerequisites. Many administrator training programs do not even require formal courses in evaluation techniques for complex issue decision-making -- or for that matter, even simple issue decision-making. Seldom are there requirements for formal courses pertaining to the understanding of computer applications to education.

None of these charges should be of any surprise to the reader, since many teacher training institutions have yet to offer formal coursework pertinent to the role of micro-computers in the classroom -- for both computer-assisted and/or computer-managed instruction -- while the schools are purchasing microcomputers and packaged CAI/CMI software at a fantastic rate. The age of complexity has truly changed from a time wherein complex questions and answers were analyzed via complex procedures, to a time (now) where the idea of complexity deals more with understanding, "why we do whatever it is we do".

## The Need For Visibility

With today's knowledge of new ways to attack and resolve old problems, and the computerized hardware and software to achieve implementation of these new ways, emerging educational administrators can (and must) become leaders in their field. They must take the initiative necessary to evaluate complex issues with an open mind -- free of the politically oriented nonsense which has brought the educational professional to the lowest rung on the professional ladder as far as prestige and trust are concerned. Today's administrator must come to understand not only the problems within education today -- but also their beginnings as well as their intended or required solutions. To not do so, is certainly the choice of malfeasance and ignorance over progress and direction.

Visibility is the key. Today's educational leader must not only be visible to the school and community served, but must in fact allow problems within that context to surface and be examined openly and totally for potential resolution. Attendance at board meetings, community organizational functions, and neighborhood meetings does little to promote visibility of any significance. That visibility which is of concern here, is the creation of an environment within which valid and reliable evaluation can be performed, and within which informed decision-making can thus be possible.

## The Need For Responsibility

Forging a milieu constructed upon the principals of openness and visibility for problem-examination and problem-solving, will produce little more than chaos and randomized schizophrenia unless there is strict order and direction to the process. The address of critical problem issues requires what many philosophers (for lack of another term) have called the 'team-player' approach.

Unfortunately, team-players in the strictest sense follow the rules of their team -- and in most games of contest, there are at least two sides. One only has to review the proceedings of many management-union negotiation meetings in order to derive a perspective of how two groups striving for the same ends can in fact destroy the process -- and often the ends sought. Unfortunately, many of today's educational crises can not (and moreover will not) be patient for such groups to resolve their political and mutual differences.

Evaluation and decisioning teams are no different. Members form sociometrical sub-teams though only a single, formal team exists. The need to initially identify direction, focus and the medium for project control can often consume several hours of meeting time because of delays associated with personal differences. The end-result of an evaluation project is not the existence of team harmony -- it is the solution of the identified problem. Team-harmony is but the process.

The key is responsibility. Educational administrators as the key decision-maker of the organizational must be responsible not only to the members of the evaluation team, but also to the constituents of the particular educational organization involved. This educational leader must not only be responsible to the community, but must also portray responsibility regarding the use and acceptance of the evaluation team, itself. While the evaluation process must be open and visible, so also must the workings of that team be left unencumbered by the adminstrator. Though certain decision alternatives may be uncomfortable or personally undesireable, the team must be left -- moreover, encouraged -- to explore each and every potential problem resolution (and its associated procedure).

## The Need For Accountability

Finally at stake in the evaluation and problem resolution process, is the issue of accountability. Whereas visibility prepares the milieu for problem resolution, and responsibility is the primary ingredient for performing the problem-solving activities, it remains the role of accountability to prepare for final acceptance of the decision(s) made.

However, accountability can not exist without visibility and responsibility as necessary allies. The visibility of an open process, available for all to scrutinize; the responsibility of executing a valid and reliable process in which various solution alternatives are explored, examined and evaluated; and preparation of materials and documentation demonstrating specifically why one solution was selected over all opponents -- signals the successful environment for valid and reliable decision-making.

## The Applicability of the Multiple Alternatives Model

As the reader progresses through this text, it will become more and more apparent as to the utility of the MAM framework in addressing each of the above issues concerned with visibility, responsibility and accountability. Complex issues demand complex

complex evaluation techniques, and ofter equally complex solutions. Without a sophisticated technique to address these problems, *solution identification and development can be extremely* tedious, and open to errors of many kinds. At the same time, if the sophisticated solution generation technique is neither understandable nor visible to the group authorizing the study, the solution resulting will never be accepted (embraced?) by the individuals requiring the identified problem's solution.

Because of MAM requirements for strict criterion definition and measurement scaling; and because each and every potential alternative solution is available for check and recheck as the system progresses toward final solution -- the multiple alternatives modeling technique is highly desireable as a strategy for solving complex problems of the multiple alternatives' type.

# SIMULATION TO STUDY FUTURE DECISIONING IMPACT

Before we move into the remaining three topics of this first chapter, and develop the general, underlying thesis of the MAM approach -- some time should be spent indoctrinating the reader to the role of simulation within evaluation and decision-making.

Simply stated, simulation means to "try something before actually doing it". The act of trying-out an idea is certainly not a revolutionary approach to problem-solving. However, some problems are of such a critical nature, that implementing a particular solution and examining its effects may result in other problems completely unforeseen to the original problem-solvers.

Simulation is a means by which the use of criterion variables which are accepted as indicative of certain environment characteristics, can assume values which are predictable of the extent to which certain types of solutions will be successful. Besides the use of criterion indicators as 'impact predictors', criterion can also be utilized to compare various potential solutions in order to select a certain subset of these possible strategies as the individual solution(s) to execute in the face of the identified difficulty. By merging the use of criterion variables to evaluate and compare identified potential solutions, with the use of criterion indicators for predicting environmental impact due to the various combinations (and permutations) of the potential strategies being examined -- the ability to simulate the future of the organization, based upon certain resolutional strategies, is possible.

Not only does the multiple alternatives modeling framework promote such simulative techniques, but it also allows the evaluator/decision-maker to vary the model's requirements for finding a solution (called the constraints for the process) -- and thus provides a format for examining a wide-range of possible solution sets based upon certain, measureable pre-requisites.

As will be illustrated within this text, the ability to input measureable characteristics of not only the potential solutions, but also the criterion indicators of the environment -- make the MAM system one of the most powerful evaluation and decisioning tools available to the educational leader today.

## CRITERION REFERENCING AND CONTROL

Decisions may be rather pragmatically viewed as the results of systematic and reality-based evaluation processes. To attain the desired 'idealogical' ends suggested by such goals as visibility, responsibility and accountability, the decision-maker must rely heavily upon various indicators which will attempt to assess the situation which requires a decision be made, measure the alternative methods and means with which to formulate a valid decision to meet that situation, and evaluate the expected impact upon that same situation of the remediation strategy selected. Thus, some means for determining the needs and demands associated with some problem, the comparative value and strength of various alternatives solutions or remediation strategies to address the problem issue(s), and the simultaneous effects of the solution to be executed -- must be defined.

### Criteria as a Reference for Determining Value

A criterion is a standard or rule by which a potential decision can be tested for its value in addressing the proposed issue; and a rational judgement result. A criterion may be as objective or subjective as the evaluator will allow; and either quantitative or qualitative in terms of its 'visual' measure. Since no decision or judgement is possible without some selected determination of value based upon need, demand, appropriateness, value, worth, expectation, etc., it is ridiculous to assume, that decisions can be made without reliance upon 'hard performance' indicators of worth, nor that complex issues can be addressed without the conscious measure, valuation and determination of strength, of the complex solutions which may be required.

The use of criteria for determining worth and strength is not relegated solely to the area of measuring, and thereby controlling, the content of indicators which will be used within a necessary decisioning situation. Equally important moreover, is the reliance upon various criterion measures for controlling the process of the decisioning procedure itself. For example, the evaluator may define several criterion indice of effectiveness and efficiency in order to compare various alternative methods for resolving the problem situation at hand; and subsequently measure these performance indicators in such a manner as to without doubt produce valid measures via reliable techniques. The process-control issue manifests itself in the situation whereupon having measured each criterion across all alternative actions, the problem becomes to determine which alternative(s) are most likely to produce the desired impact upon the system without introducing additional 'new' problems to related system components. No single or multiple decision(s) will provide total positive benefit to the system, without likewise introducing some amount of negative by-product -- there is both good and bad in all decisions, and the extent of these factors must be observed and controlled for in the decisioning situation.

## Criteria as a Reference for Controlling Evaluation

The issues involved in the control of evaluation procedures address two specific areas: the control of positive and negative influence expected via the adoption of various alternative solution strategies; and the control necessary for determining the necessary 'amount' of solution required to effectively solve the problem being analyzed.

The control of positive and negative impact to the system as a whole, based upon the positive and negative influences associated with a particular solution (or set of solutions), is directly related to the idea of preference and trade-off in decision-making. We "prefer" to have our decision affect the system in specific ways, and we "prefer" to have the solution exhibit certain other qualities which may be directly or indirectly related to the problem being resolved. However, we are also realistic enough to understand that some 'give and take' will be necessary for the final acceptance of a particular solution (or set of solutions). Such "trading-off" manifests itself in many ways, but is normally recognized in two particular instances. In a differentiated sense, the decision-making will define certain limits for each of the criterion variables which will be utilized in determining the value of a particular solution. Such individual limits will normally be concerned with only expected negative impact to the system based upon that particular alternative solutions being selected as the final decision. If such limits are placed upon positive impact, they will always be defined as 'lower bounds' or 'basal minimums' which the particular alternative must surpass.

The second instance regarding a "trade-off" manifestation addresses the integrated sense in controlling for simultaneous positive and negative impact to the system, based upon the final solutions selected. For this requirement, collective rather than individual impact to the system based upon the defined criterion indicators will be assigned limits. Therefore, a final group of decisions may be viewed as acceptable, based upon not only their high positive impact to the system, but also their low negative effect. In fact, some solutions may be more acceptable based upon a low negative impact and a medium positive effect, as compared to a solution which projects high positive benefit while presenting some unacceptably medium negative impact to the same system, or one of its inter-related components.

The necessity of some integrated-form of evaluation control is even more predominate in a situation, where multiple solutions will be required to remediate the final problem. The final set of solutions (final decision) selected will exhibited an often widely diverse range of positive and negative impact to the system. Differentially, each final solution will satisfy the minimum positive requirements and the maximum negative limits set a prior by the evaluator. Integrally, the combined positive and negative effects associated with the full range of solutions will in total be acceptable to the decision-maker, and therefore to the system as a whole.

## Defining Multiple Criteria in the Generic Sense

The necessity to define and measure various criterion-referenced indicators for controlling the evaluation and decisionmaking framework(s) is without question (?) one of the most rigorous and demanding of all evaluation skills. It has been approached many ways by as many people -- sometimes systematically and sometimes not -- but always with specific requirements in mind. It remains these 'requirements' that have often resulted in the misuse or abuse of the criterion-referenced process for decision-making; and presents the most formidable obstacle for the acceptance of a criterion-referenced process in evaluation.

While few individuals would state, that criteria are not necessary for responsible, etc. evaluation and subsequent decision-making, many people will take the position, that criterion determination, definition and measurement are impossible tasks, fraught with the "uncontrollable dangers" of invalidity and unreliability. It has continued to be of curious (and sometimes humorous) interest to the author, that the critics of criterion-referenced decisioning denounce those components of evaluation and decision-making which the criterion-referenced model seeks to control and validate. The real obstacle of course, lies in the trust which must exist between the 'evaluation modeler', the 'decisioner', and all those 'systemettes' impacted via the decision(s). Basically, only high visibility and accountability will forge the trust needed for the final acceptance of the decisions made. Visibility will result necessarily from keeping both associated and interested parties informed of the techniques, procedures and their outcomes. Accountability can be much more precipitous matter however, and will demand much more than openess, in order to gain the necessary acceptance of the evaluation process.

Accountability in this sense requires the evaluation and resulting decisions to "take into account" all those ingredients which are seen to impact upon both the decisioning process, and upon the effect to the system associated with that decision. Evaluators have forever been confronted with the question (or ploy): "But what if this criterion was taken into account ... would there be a difference in the particular solution selected?". Therefore, decision-makers must be prepared to: first, incorporate all criterion references which are expected to impact upon the solution to be evaluated; and second, introduce further measures on the request of other individuals, in order to examine whether any differential impact upon the solution(s) chosen results.

In order to begin the criterion definition or generation process, the evaluator must commence with a somewhat general idea as to what references will be necessary to adequately address the issue of utilizing performance indicators to measure the full set of prospective or potential alternative remediation strategies. These general references, or what can be referred to as the generic set of criterion references, will provide a theoretical, modeling base by which the evaluator will be able to define more specific (i.e. species-related) criterion indicators for direct measurement. For most purposes, this generic set will be comprised of two subsets: generics which model the system for which the resulting decisions are necessary; and generics which model the various alternative solutions which have been formulated to solve the problem(s) associated with that system.

System-generic criterion-references can be defined as those measures of need and demand. That is, the need of the system for some form of remediation based upon certain measures of criteria which will demonstrate that need; and the demand of the system for relief -- their perception of what the system needs -- for direct comparison to the (hopefully) more objective measures of need. It should be noted, that some evaluation situations will require an additional and separate measure of performance (i.e., current functioning) in order to directly understand the relationship of demand and need in the generic sense. However, most situations will be able to 'construct' a measure of performance, simply by comparing the current demand placed upon the system; and the perception of need which exists from within the organization or system as a whole.

Solution-generic criterion-references can be defined as those 'performance' measures of effectiveness, efficiency, expenditure, and satisfaction. Generally, the comparative analysis of prospective decisional alternatives will require measures of: (1) what the strategy or tactic will accomplish; (2) how the alternative will resolve the dilemma; (3) how many resources must be committed to implementation; and (4) how satisfied we will be with the process and the result. Many species-oriented criteria may be required to address each of these four solution-generic issues (as well as those for the two (or three) system-generics). The true utility of these generic indicators lies in providing a theoretical model for generating the more specific criterion measures which will be input to the evaluation process.

## An Illustration of the Criterion-Reference Generation Process

In an earlier work (Wholeben, 1980a), a demonstration of the process for generating necessary criterion forms for evaluating schools sites for closure, will serve to illustrate the issue of defining criterion-references for decision-making. This particular illustration goes one step beyond the discussion earlier in this section, in that the criteria defined for school-site-closure decisioning represented a "cross-comparison" between certain references utilized in business and industry for site comparisons, and their relative usefulness within the educational sector.

A total of 34 criterion-references were discerned from a review of the relevant business and industrial applications, and collapsed into six collective categories as follows:

[1] characteristics of the physical plant
(9 criteria);

[2] location of the site
(4 criteria);

[3] characteristics of the surrounding neighborhood
(6 criteria);

[4] employee (or faculty) information
(5 criteria);

[5] customer (or student) information
(4 criteria); and

[6] production (or curriculum) requirements
(6 criteria).

Each of the subsets of criterion references were defined to match the cross-comparative relationship between the business or industrial section, and the educational domain. The full set of criterion references has been reviewed beginning on the following page.

The reader will see many indicators of our previously defined generic forms: need, demand, performance, effectiveness, efficiency, expenditure and satisfaction -- within the references illustrated. What the reader will not witness, however, is a directly discernible process for generating the criterion forms. In other words, no procedure will ever replace the knowledge and experience of the evaluator in generating indicators for future measurement. A theoretical model based upon generic standards will serve only to guide thinking, and hopefully alert the evaluator to areas which will require representation within the evaluation process. No computer program to date has been written to generate criteria for future decisions based upon a few entered keywords ... but we're working on it.

# || CRITERION CONSTRUCTS FOR TARGETING SCHOOL CLOSURES ||

(Relating Industrial and Educational Domains)

## CONSTRUCT #1: THE PHYSICAL PLANT

### [SIZE OF FIRM OR BRANCH]

| | |
|---|---|
| ‹Industry› | size of firm or branch reltive to current consumer demand |
| ‹Education› | capacity of educational site and the current/potential enrollment trend(s) in the attendance area |

### [TYPE OF CONSTRUCTION]

| | |
|---|---|
| ‹Industry› | relationship of physical construction to other existing criterion variables |
| ‹Education› | characteristics of plant construction in relation to remaining criterion estimates |

### [AGE/CONDITION OF SITE]

| | |
|---|---|
| ‹Industry› | relation of plant age and current condition of facility to other criterion estimates and on-going operations |

| | |
|---|---|
| ‹Education› | impact of school condition and age upon facility costs and academic requirements |

[COST OF SITE AND PREMISES]

| | |
|---|---|
| ‹Industry› | property costs associated with purchasing and/or leasing current site/premises; and subsequent maintenance of site for future production |
| ‹Education› | current principal and interest costs associated with school plant |

[TAXES]

| | |
|---|---|
| ‹Industry› | loss to profit margin due to existing regional tax structure |
| ‹Education› | increase to overall budgetary requirements due to tax requirements |

[UTILITY RESOURCE REQUIREMENTS]

| | |
|---|---|
| ‹Industry› | demand upon natural and converted resources for production and operation |
| ‹Education› | requirements of heating and lighting utilities for facility operation |

[UTILITY RESOURCE COST EXPENDITURES]

| | |
|---|---|
| <Industry> | current fiscal expenditures for resource resource requirements |
| <Education> | current fiscal expenditures for utility requirements |

### [ROOM FOR EXPANSION]

| | |
|---|---|
| <Industry> | feasibility of site expansion due to increased product demand |
| <Education> | amount of 'non-facility' grounds available for construction additions without off-setting existing playground area(s) |

### [SECURITY RISK]

| | |
|---|---|
| <Industry> | characteristics of plant and surrounding area promoting security of facility |
| <Education> | degree of school complex security fostered by physical construction and neighborhood location |

## CONSTRUCT #2: THE LOCATION OF THE FACILITY

### [INDUSTRIAL CONCENTRATION]

| | |
|---|---|
| <Industry> | present and/or proposed concentration of parallel competitive activities within the marketing area under consideration |

| | |
|---|---|
| ‹Education› | ratio of existing educational outlets (schools) to the localized supply of available school-aged children |

## [TRANSPORTATION DISTANCE]

| | |
|---|---|
| ‹Industry› | transportation distance of goods and services between production site(s) and various supply and distribution centers |
| ‹Education› | transportation distance of students within assigned attendance zone to respective school site |

## [TRANSPORTATION COSTS]

| | |
|---|---|
| ‹Industry› | incurred costs of transporting goods from production centers to distribution outlets |
| ‹Education› | expenses associated with required busing (e.g. special education, desegregation, etc.) and remote-residence transportation of students (residences beyond established walking-distance regulations) |

## [REMOTE OR RURAL LOCATIONS]

| | |
|---|---|
| ‹Industry› | effect of dependence upon required utility facilities not immediately available to a remote production center |

| | |
|---|---|
| ‹Education› | effect of skewed student-residence (location) distributions upon centralized school site location within perimeter attendance areas |

## CONSTRUCT #3: THE NEIGHBORHOOD

### [RESIDENTIAL HOUSING AVAILABILITY]

| | |
|---|---|
| ‹Industry› | potential residential construction and effect upon consumer characteristics |
| ‹Education› | potential residential construction and impact upon future school-aged populations |

### [AREA INDUSTRIES]

| | |
|---|---|
| ‹Industry› | compatible local industries as positively influencing the growth (or stable margin) of consumer magnitude |
| ‹Education› | availability of local industries promoting family residential magnitudes (e.g. fire and police protection, groceries, churches) |

### [RELATED EMPLOYMENT OPPORTUNITIES]

| | |
|---|---|
| ‹Industry› | availability of neighboring industries (business, industry, schools) to provide additional income possibilities for dual-employment families |

| | |
|---|---|
| ‹Education› | availability of employment opportunities for related spouse occupational interests |

### [AUXILIARY FACILITIES]

| | |
|---|---|
| ‹Industry› | availability of related secondary interests to consumer population (e.g. deprived area regarding new employment source) |
| ‹Education› | Extent of school facility utilization for extra-educational affairs (e.g. community meetings, recreation center) |

### [ENVIRONMENTAL IMPACT]

| | |
|---|---|
| ‹Industry› | impact of plant site and production operations upon surrounding area (e.g. quality air control, extent of vehicular traffic, property values, tax bases) |
| ‹Education› | relation of neighborhood school to surrounding residential area (e.g. property values and tax base, residential construction, relocation of supporting industries) |

### [INTER-INDUSTRIAL PLANNING INDICE]

| | |
|---|---|
| ‹Industry› | extent to which surrounding non-competitive industry planning foci match current research and development data |

‹Education› use of community and regional (city, county, state) planning data to assist educational decisioning

## CONSTRUCT #4: THE FACULTY/EMPLOYEE POPULATION

### [ENTREPRENEURIAL AND EXECUTIVE PERSONAL PREFERENCE]

‹Industry› management-based objectives in the design, production and supply of separately, manufactured goods

‹Education› curricular and instructional demand of school administration related to professional biases

### [MANAGEMENT AND TECHNICAL STAFF]

‹Industry› availability of and present average costs for management associated with desired production levels

‹Education› characteristics and salaries of school administrators associated with instructional foci and parental demands

### [LABOR]

‹Industry› availability and present average costs of labor associated with desired production levels

| | |
|---|---|
| ‹Education› | characteristics and salaries of teacher staffing and emphases associated with instructional foci and parental demands |

### [PRODUCTION COST COMPETITION]

| | |
|---|---|
| ‹Industry› | relationship of resource requirments to production output |
| ‹Education› | allocation of budgetary requirements related to class size, teacher load, and curricular attainment |

### [EDUCATIONAL FACILITIES]

| | |
|---|---|
| ‹Industry› | availability of external training and in-service resources for improving production and supply |
| ‹Education› | availability of higher education facilities for improving staff knowledge and instructional techniques |

## CONSTRUCT #5: THE CONSUMER/STUDENT POPULATION

### [PROXIMITY OF RAW MATERIAL SUPPLIES]

| | |
|---|---|
| ‹Industry› | accessibility fo raw material and supplies to manufacturing location |

| | |
|---|---|
| ‹Education› | proximity of students within walking distance of school site |

### [BUSINESS GROWTH]

| | |
|---|---|
| ‹Industry› | current business trends in consumer population and related demand potential |
| ‹Education› | projected student enrollemnt based upon recent attendance trends |

### [CONSUMER DEMOGRAPHIC CHARACTERISTICS]

| | |
|---|---|
| ‹Industry› | consumer demographic characteristics for future trend forecasting |
| ‹Education› | trends of family size, etc., for predicting future enrollment potential |

### [AFFIRMATIVE ACTION]

| | |
|---|---|
| ‹Industry› | current (and proposed) level of federal guidelines' compliance |
| ‹Education› | current perspecti relating to desegration and minorities (including handicapped, special education) committments |

## CONSTRUCT #6: THE PRODUCT MARKET (CURRICULUM & INSTRUCTION)

### [MARKET PULL AND MARKETING STRATEGIES]

| | |
|---|---|
| ‹Industry› | consumer demand (market pull) and manufacturer's planned focus of supply (marketing strategy) |
| ‹Education› | curricular demand emphases (basics curricula, individualized instruction, special education) of parents in attendance area, and the current (and potential) availability of such academic activities within the school |

### [LABOR STABILITY]

| | |
|---|---|
| ‹Industry› | turnover history and/or projected availability of technical staff in production (labor, etc.) |
| ‹Education› | trend characteristics of instruction staff parallel to established instructional objectives |

### [FACILITY UTILIZATION]

| | |
|---|---|
| ‹Industry› | extent of current production utilization of existing plant resources |
| ‹Education› | degree of academic and co-curricular utilization of existing school facility |

| | |
|---|---|
| | resources (e.g. class space, specialized instructional areas) |

### [PRODUCTION INDEX]

| | |
|---|---|
| <Industry> | current rate of production output based upon existing resources and/or facilities |
| <Education> | level of academic attainment based upon current curricula and instructional strategies |

### [AUXILIARY USE OF FACILITIES]

| | |
|---|---|
| <Industry> | amount of existing specialized plant equipment which is essential to the missioni of production |
| <Education> | existence of specialized facilities integral to the academic process (science laboratory, swimming pool, built-in A.V. equipment) |

### [ACCESSIBILITY OF PREMISES]

| | |
|---|---|
| <Industry> | availability of production site to supply/distribution centers, and of distribution centers to consumer |
| <Education> | flexibility of school site (adaptiveness) to incorporate multi-dimensional curricular interests and instructional goals |

# OPERATIONS RESEARCH AND THE EVALUATION OF FEASIBLE ALTERNATIVES

Chapter two (following) will devote much of its content to the exposition of budgeting and funding as a structural allocation-oriented activity. A position will be taken which will specifically adhere to the philosophy that fiscal modeling (i.e. the simulation of a fiscal decisioning system) must be criterion-referenced to the actual (real-life) system; and that these criteria should be designed in such a way as to perform three vital functions:

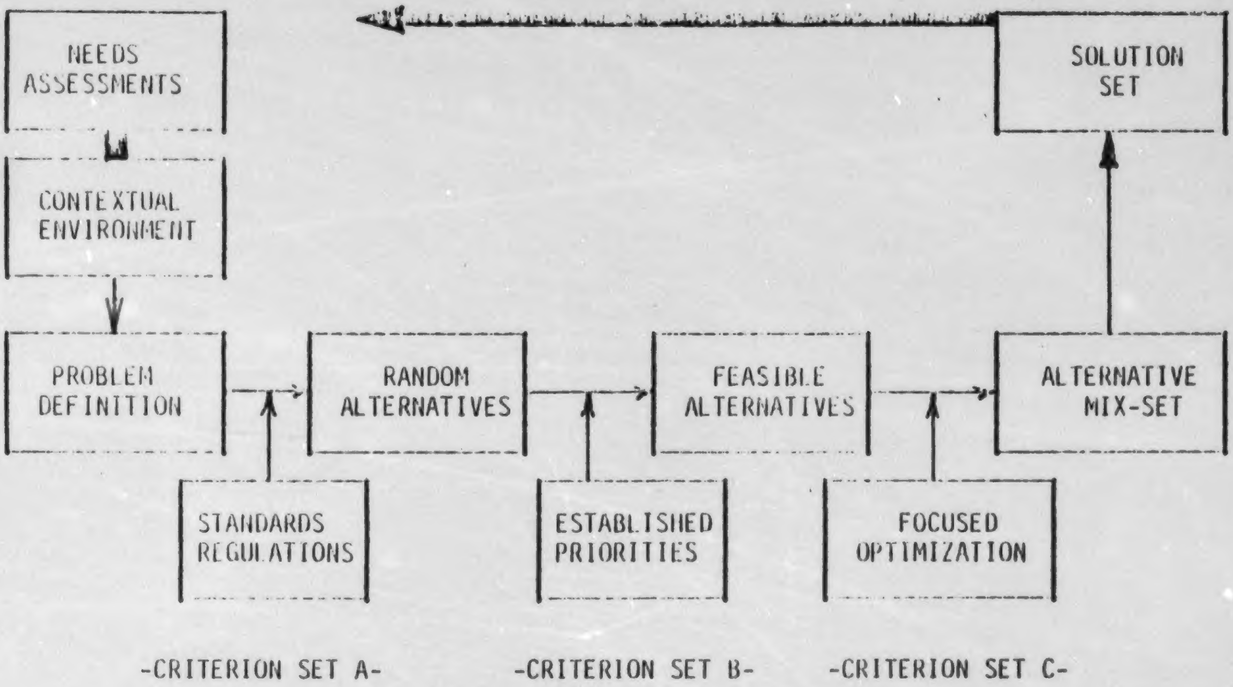
(1) to reliably represent the true system being modeled (simulated);

(2) to validly represent those factors (inputs, outputs, processes) which are required (and desired) to provide the necessary information in order to make decisions);

(3) to totally represent the impact to the system (as a whole) of the potential alternative decisions being evaluated.

The remainder of Chapter one will (premeditatively) focus its energies upon preparing the reader to view the fiscal crisis situation, and its potential demand for fiscal roll-backs, as an illustrative framework for multiple alternatives decision-making. In this case the alternatives are defined as either all possible programs (sources of expenditure) or significantly distinct parts of programs which might be discontinued and therefore deallocated from the existing budget; that is, rolled-back in order to balance the budget. To evaluate these many alternative, potential sources of cutbacks, criteria are required which will not

Figure 4. Representation of a Sequencial, Criterion Referenced Model for Systematically Developing a Multiple Alternatives Solution Set.


NEEDS ASSESSMENTS
CONTEXTUAL ENVIRONMENT
PROBLEM DEFINITION
RANDOM ALTERNATIVES
FEASIBLE ALTERNATIVES
ALTERNATIVE MIX-SET
SOLUTION SET
STANDARDS REGULATIONS
ESTABLISHED PRIORITIES
FOCUSED OPTIMIZATION
-CRITERION SET A-
-CRITERION SET B-
-CRITERION SET C-

only describe the attributes of each alternative in terms of its contributions to system function (or lack of such contributions), but will also demonstrate the costs (object category expenditures) associated with each of the alternatives. The overall goal then is to select those alternative programs (decisions) which may be feasibly and rationally rolled-back without providing major detriment to the system's required functioning, while satisfying the reduced budgetary limits imposed by the fiscal crisis.

## Optimal Decisioning Within a Constrained Feasible Space

Any decision, viewed as the best possible alternative course of action to operationalize, must by definition be optimal; that is, all things considered, this action posits the best interests of the organizations or system being modeled. Simulation of these "things" and "interests" results from the use of criteria to measure the value of each alternative and its impact upon the system as a whole -- that is, how the system is constrained by these criterion measures across all alternatives. Such measures are referred to as criterion constraints. Those alternatives decisions (when evaluated) will display degree of optimality ("best"-ness) in addressing the solution to the problem defined; but first, each particular alternative must itself be a reasonably potential solution to the problem; that is, exhibit the quality of feasibility.

The context of decisioning alternatives is thus a rather interesting flow from a traditional needs assessment (What is the real problem? that is, not the system of the underlying problem) to the determination of a set of solutions to be implemented via a criterion-referenced model of value and worth, versus impact. <Figure 1> schematically depicts this (obviously interesting) flow.

After the real problem is determined, dissected and defined (the 3-D's), standards and regulations (operating goals) of the system become the first set of criteria to impact the simulation. Standards provide the necessary data to assist construction of all possible alternative sources of action the decision-maker must consider and evaluate (i.e. the set of random alternatives). Next, established priorities are defined and developed into a set of criteria which allow further scrutiny of the random alternatives, and their measured impact upon the decisioning system. Often times, an alternative may be "possible" but not "plausible" due to certain established priorities. Alternatives which survive this recent criterion-focused evaluation become known as feasible. Finally, the more important (weighted) criteria are drawn into the evaluation in order to focus the optimization standards for the decisions about to be made (that is, selection of alternatives).

The potential existence of an alternative mix-set focuses once again upon the idea of singular versus multiple alternative(s) frameworks. Recall that a singular framework involves the choice of one and only one (or none, of course) alternative course of action based upon the evaluative criteria used. A multiple alternatives' setting permits the choice of a group of several alternatives that when implemented as a group (not necessarily simultaneously), produce the desired process and attain the required result.

## Fiscal Allocation as a Multiple Alternatives Problem

Fiscal crises provide the budget manager and program administrator with a unique experience, "to accomplish more for less". Though tongue-in-cheek, the unfortunate reality of today's economy and our best program prognostications for the future point to a steadily decreasing funding base. Decreased funding will not however be followed by the public's reduced need for educational services, either in quantity or quality. Organizational philosophies, goals and needs will stay relatively constant; yet with a new demand for prioritization and demonstrated accountability. After 25 years of no-holds-barred development and spending, can education 'equally' meet the new demands for austerity and roll-backs, in light of declining enrollments, school closures, a sagging national economy and the ever-increasing demand by teacher for higher salaries?

Whether the problem be one of fiscal allocation or deallocation, the funding framework for program budgeting is a multiple alternative modeling problem. Consider the need to determine which programs are to be funded within established budgetary limitations; and therefore, which programs will not. This is obviously a decisioning situation, whereby the goal is to fund as many programs as possible within the prescribed budget, based upon: (1) each program's merits, (2) the overall system's needs, and (3) the impact of the alternatives -- individually and collectively -- upon system functioning as a whole. Each alternative's merits (type and extent) will be measured via the various criteria which have been a priori identified as demonstrative of the system's definition of 'merit' or 'impact'. Finally, the cost for every aspect of each program is computed; and entered as a measure of impact to the system's budget, in deciding to implement the program (expenditure) or not (savings; with an opportunities cost).

Concisely stated, the fiscal allocation between multiple, competing programs assumes the following direction:

> To choose (and therefore also fail-to-choose) some finite number of programs from among the available alternatives --

Figure 5. Fiscal Allocations as a Multiple Alternative Problem, Utilizing the Decision Matrix Framework.

Multiple Alternatives

| Criteria | | Prog1 | Prog2 | Prog3 | . . . | Progn | |
|---|---|---|---|---|---|---|---|
| Positive Impact | 1.__ | +11 | +12 | +13 | . . . | +1n | |
| | 2.__ | +21 | +22 | +23 | . . . | +2n | Maximize |
| | 3.__ | +31 | +32 | +33 | . . . | +3n | |
| Negative Impact | 1.__ | -11 | -12 | -13 | . . . | -1n | |
| | 2.__ | -21 | -22 | -23 | . . . | -2n | Minimize |
| | 3.__ | -31 | -32 | -33 | . . . | -3n | |
| Specific Costs | 1.__ | $11 | $12 | $13 | . . . | $1n | |
| | 2.__ | $21 | $22 | $23 | . . . | $2n | Sum < total budget available |
| | 3.__ | $31 | $32 | $33 | . . . | $3n | |

each alternative associated with measures of merit, worth, impact and cost -- such that:

1. total (collective) positive impact to the system is maximized (meeting needs, goals and interests);
2. total (collective) negative impact is minimized (not meeting needs, etc.); and
3. total (summed program budgetary demand does not exceed the amount of available monies.

<Figure 2> provides a simple outline of the above stated goal(s).

While resembling the traditional cost-benefit analytical framework discussed previously, <Figure 5> once again affirms the demand for an evaluation tool which is capable of analyzing the role(s) of multiple alternatives across multiple criteria; and selecting those alternatives which best fit the criterion-constrained system (decisioning matrix). Again, we are faced with the issue of interactive-effects modeling.

## Interactive Effects Modeling

There exists an fundamental need to understand the interactive nature of selecting from among multiple alternatives; that is, the total combined effect of one choice based upon the various values of each alternative's criterion measures; and the desire to choose that set of alternatives which demonstrates a collective composite of acceptable criterion values. This is complicated by the fact that different combinations of alternatives are possible in forming the final solution set. Simply (?) stated, such a decisioning requirement is a nightmare. But can a technical strategy be formulated to address equally the issues of technique as well as the fiscal allocation problem itself?

Welcome to the world of operations research!

## The Operations Research (OR) Approach

Operations research as a scientific investigation and evaluation tool, views the milieu of decisioning as a criterion-referenced choice between stated alternatives. The term "operations research" is itself a generic label for several actual tools, and states that a decision situation can be modeled (simulated) mathematically. The multiple alternatives model employs a particular subset of the OR approach, called binary integer programming, which utilizes systems of simultaneous linear inequalities (roughly equivalent to high school intermediate algebra).

Via an algebraic representation of the specific decisioning framework, where each criterion is represented as a linear inequality (the independent variables as the programs, and the dependent variables as the total system impact), a value of '1' (i.e. to choose) or '0' (i.e. to not choose) can be assigned to each of the independent variables (alternative programs). The best mix of 1's and 0's (across all multiple alternatives) is the most optimal solution set. Thus if Program 1 = '1', Program 2 = '0' and Program 3 = '1' (of only three program alternatives) the decision is to fund programs '1' and '3'; and therefore not fund program '2'. This is the basis for the multiple alternatives modeling of a fiscal roll-back situation.

## SIMULATION MODELING WITHIN A CRITERION-IMPACT DESIGN

The theoretical mathematician would say that in the situation of fiscal roll-backs and the use of multiple alternatives modeling in performing such decisioning -- the need to determine roll-backs is the necessary condition and the utility of the MAM technique the sufficient condition -- for the existence of the multiple alternatives modeling technique. However,the total utility of this model extends beyond the ability to provide decision-makers with concrete decisions based upon a criterion-impact design.

Consider the ability (of the decision-maker) to test various hypotheses as to how certain groups of alternatives would impact the system. Consider further the ability to vary the system's parameters (needs, goals, demands, etc.) and observe the differences (if any) of programs selected for funding, based upon the newly modified constraints. Such abilities suggest a setting in which the decision-maker can accurately (validly and reliably) model a system which may not yet exist. It is the tripartite ability to represent a system, experiment with alternatives (programs funded and/or criteria utilized) and predict with some certainty the results of alternatives actions. This is operational modeling in the "crystal ball" setting, or simulation.

The reader may be musing, "True, but so much of the confidence placed in the results of such a simulative model must itself be based upon the assumption that the model indeed 'models' the actual operational setting, both validly and reliably." Obviously, indisputable. Yet, all of educational research was at one time (if not still) held to be non-utilizable due to the inability to control all mitigating and extenuating forces which convoluted curricular learning, management style and teacher attitude findings, ad nauseaum. Recalling that the multiple alternatives modeling technique (as in other simulative frameworks) seeks only to assist the policy analyst's understanding of data to be used in the actual decision-making (regardless of how), we feel confident in saying, "Try it, you'll like it." In today's educational climate, where experimentation with policy is often times both involved and hazardous to one's professional health, the MAM framework can with obvious effort and diligence uncover the projective relationships between program alternatives, criterion impact to the system, and budgeting constraints.

## Monitoring System Impact of Selected Alternatives

A final note must be made for fiscal modeling under implementation; that is, what to do when the choices have been made, and all decisions are 'go'. 'Borrowing' as we educational systems' planners did from the electronic engineers during the late 1960's, the issue of systemic cyberneticism once again becomes useful. Cybernetic qualities of any modeling stragegy simply refers to a careful monitorization of the real system under implementation, as you put your fiscal roll-back decisions into effect. Now, and heretofore unforseen consequences, impact, criterion-references and measurement techniques may be discovered, which can be integrated within the original modeling framework; that is, as a new linear constraint equation or inequality.

The utility of fine-tuning a decisioning model for more accurate future use is certainly moot. As in multivariate regression, the model developer may have to try new criteria constraints (variables) to associate their variance patterns with the decisions modeled, and the resulting impact(s) of the decisions made.

# CHAPTER 02

# THE CONTEXTUAL STAGE

[ Modeling Budgetary Roll-Backs for
Multiple Alternatives Analysis ]

# INTRODUCTION TO MAA MODELING FOR BUDGETARY ROLL-BACKS

This chapter explores the philosophical rationale underlying the modeling of fiscal alternatives in response to budgeting cut-backs; and provides a foundation for viewing the program funding/allocation decision as either an 'allocation' question (i.e. giving to) or a 'deallocation' question (i.e. taking away). To illustrate the rudiments of decision modeling, the basic trends of the traditional cost/benefit model are defined and discussed, especially with regard to applying multiple, competing criterion measures across multiple (potential) alternatives solutions. The four main criterion foci of effectiveness, efficiency, satisfaction and expenditures are discussed relative to multiple decision evaluation; and the ideas of preference and trade-off (compromise) necessitated by the existence of multiple criteria in competition with one another are summarized. Finally, the application of operations research techniques as a tool for evaluating potential alternatives is presented for the reader's understanding.

Chapter two prepares the reader for the technical discussion (to follow in Chapter four) regarding the actual construction of the multiple alternatives model (MAM), through the development of a MAM-orientation in a fiscal budgeting (allocation, etc.) situation. Thus this development is situation-specific (to fiscal management) and will hopefully facilitate the understanding of the MAM decisioning context. This parallel theoretical-application discussion will hopefully allow the more discerning reader to view the wide-range of application(s) available to the multiple alternatives design. The reference bibliography at the conclusion of this text will allow the masochistically-inclined reader the ability to read more in the subject of fiscal budgeting and decision-framework for analyzing allocation strategies.

# PHILOSOPHICAL FOUNDATION FOR FISCAL MODELING

Fiscal modeling refers to the studying of an environment in which some decisions are required concerning funding allocations and expenditure control. Practitioners assume that allocation by itself is an automatic interval-control for expenditure. Forgotten (or consciously misplaced) is the notion which goes beyond the question of "how much spent, totally", to the more provocative and accountable inquiry, "how much spent, *how* (in which ways), and *where*, totally". The decisions required in order to fund certain programs in lieu of other (equally deserving) programs necessitates that the decision-maker (allocator) understands *what* monies will be spent *where*, *how* and *why*; and in addition the impact that such expenditure will have upon the total (e.g. district) program in philosophy as a whole. To understand such impact (both validly and reliably) and to be able to make the decision(s) required, certain requirements are mandated.

First, an obvious need exists to define, develop and measure various criterion-variables in order to be able to compare the alternatives; and measure the impact of their funding versus non-funding to the system as a whole. For example, women's athletic programs in higher education have been highly subsidized on some campuses by income from the men's collegiate-varsity sports programs, and from other specially ear-marked funds out of the general student-programs administration budget. As budgeting cutbacks become a fiscal reality in higher education, and increased costs aggravate the existence of less monies, the women's sports program becomes a likely candidate for 'cutback' or complete defunding (cut-off). A sample of the impact-criteria required by this decisioning situation might be noted as:

(1) measures(s) of total savings, delineated into sub-expenditure (object codes), so that the worth of each 'savings' (or 'expenditure') area is known;

(2) measure(s) of total impact to the prevailing campus philosophy of equal opportunity, equity and affirmative action; and

(3) measure(s) of relative worth in retaining or discontinuing this program, compared to other programs (alternatives) which could provide equal revenue savings (eg. campus and grounds maintenance, security, remedial ("bone-head") lower-division courses.

It should be clear that two factors are operating in any MAM-decision. First, the need exists to maximize the positive impact to the system, while minimizing any negative by-products. Second, there must be a near-exhaustive (though empirically impossible) collection of criteria through which to measure both positive as well as negative impact. In reality, it becomes (itself) a goal of the model builder: to utilize the best kind(s) and most type(s) of criteria in order to validate model results.

## Maximizing Program Goals Within Budgetary Limitations

Funding cutbacks relate both to the specific form of program (e.g. student activities, gifted education, transportation) and to the more generic definition in which the collection of all programs becomes the 'program' of a higher order (e.g. the same district program). In maximizing the 'good' and minimizing the 'evil', the decision-maker must be alert to which level of program is being referenced. Obviously a criterion related to the co-curricular portion of a student ectivities program,

> "to maximize the quantity and extent of each student's participation within co-curricular activities,"

may have greater weight to the SBG/ASB advisor than to the principal who needs a higher funding level for a 'back-to-basics' remedial curriculum.

At either level, the focus is identical:

> "to maximize program goals within budgetary limitations",

while minimizing the impact of any budgetary cutback decisions to the system as a whole. Fiscal modeling thus takes on the appearance of a system of compromise -- that which is possible versus that which is desired. By juxtapositioning maximal benefit against minimal harm, each fiscal alternative's "weight" and "importance" become readily apparent, and available for comparative evaluation.

## Partial Defunding v. Selective Deallocation

Parallel to the discussion on maximizing program goals (desired outcomes) within established budgetary limitations is the economic notion of a 'break-even point'. Often times, the educational decision-maker announces a cut-back decision on a percent (or percentage) decrease in allocations. The program chairs are advised to "do their best with less", often without reflections upon whether the resulting limits placed upon program goals can be realistically achieved. At some point (the 'break-even point') reduced expenditure (reduced funding) results in program performance occuring below acceptable program goals; and thus opens a forum for discontinuing that program's operation which would then result in the savings of the total potential expenditure. The decision-maker must take into account, however, the potential of negative outcome to the system; and thereby consider an increase of funding to that particular program, with commensurate decrease to another program(s).

Clearly, this decision process is complex. Not only must all combinations and permutations of the programs being compared (multiple alternatives) be analyzed, but the system impact of each combinatorial permutate must also be assessed across all criteria. (Sounds frightening, does it not?) This line of thought is further aggravated by the aforementioned notion of "multiple funding levels" per program. Yet as hopelessly ridiculous as it may appear, the decision must be made -- and is being made in every funding cycle of every district.

Two avenues of approach to the allocation decision may be made. First, reduced funding allocation is permissable if and only if the resulting reduced allocation does not "significantly" (or magnitudinally) lower both specific and generic program goals, below some agreed-upon acceptable level. That is, why fund a program that cannot fulfill its program goals at a reduced expenditure level? The second approach however is a more direct maneuver than the partial defunding approach, and can best be described as selective deallocation.

Consider the various multiple alternatives as specific programs whose collective outcomes form the district's generic program orientation. Further, consider that some of the programs are modeled at "full-funding", some at a "minimally-acceptable level", and others at some discrete point in between. The decision now becomes to fund (allocate) at full or acceptable levels, or not at all. This focus upon selective deallocation is of the utmost importance, in order to provide a control for regulatory accountability to the decisioning framework.

## Funding Allocation v. Regulatory Accountability

The virtue, "better to give than to receive" cannot be applied to fiscal allocation cutbacks during budgeting crises. As was said in the preceding sub-topic, some distinguishable point must be defined beyond which a cut-back decision automatically becomes a deallocate ("cut-back") decision. Such decision-making must come from the generic-program administrator; the specific-program chair is not likely to voluntarily offer such suggestions. But since it is true, that "it is easier to give than to account for", the necessity for some form of regulatory accountability is obvious.

The major concern in this regard is of a volatile, political nature. The decision-maker must take initiative in determining the level of acceptable funding, and moreover operationalize the stance that at some "defined" point, the program will be deallocated instead of partially defunded. It is the opinion of the authors that all fiscal roll-back decisions be made under a discrete deallocation philosophy, rather than a progressive partial defunding scheme. Such a structured, disciplined approach is more than offset by the enhanced accountability to the modeled fiscal system.

## Full Systems' Orientation To Input

A model of a fiscal system, assisting the decision-making framework for selecting programs to be funded or defunded (rolled-back) is only as reliable as its ability to simulate that system. Reminiscent of the days of systems' planning, organizational development and participative management, a fiscal system's model must so accurately simulate the original environment, that any influence (criterion-related) to the real system is also influential to the fiscal model (i.e. validly modeled). Furthermore, output from the systems' model due to modification of those criterion-variables explaining (constraining) the simulated framework, must also reflect the changes expected to the real system (i.e. reliably modeled). Such a one-to-one correspondence between reality and simulated model requires a full systems' orientation to input.

Input to any model simulation refers generally to the effect imposed upon the model by the criterion-variables used to exemplify the real system; such criterion-referenced measures are known as constraints. The utility of full systems' constraints in accurately and consistently modeling reality is witnessed in three areas. First, the real system is controlled by the main and interactive effects of input from innumerable sources, both internal and external to the system. In the multiple alternatives context, such sources are modeled via the use of multiple competing criteria. Although certain sources may be more influential (i.e. weighted) than others, nevertheless no single input (effect) exists in isolation from the co-related effects (inputs) from other sources.

Secondly, the source of multiple criteria may itself come from multiple sources throughout the system. For example, in deciding upon a certain curricular program for implementation, a reasonable criterion measure would be the extent of perceived effectiveness in instituting the designed learning change. Such perceived change however might be different for each individual subgroup: teachers, administrators, students and parents. Although a measure of 'learning affectiveness' is desireable, necessary also will be the modeling of a decisioning process where each of four sources are modeled independently (though simultaneously). If the model were to use only a single constraint to input a composite measure of effectiveness, the original variance between the five groups would be lost; and the system inaccurately model the environment surrounding the decision.

Finally, a full system's orientation to input must be modeled so as to allow an ability to compare inputed criterion measures (constraints) across the alternative programs. Only then can an adequate "consensus" model be developed to portray these system sources of impact.

# PROGRAM BUDGETING FOR AN ALLOCATION/DEALLOCATION FISCAL STRATEGY

The reader will recall that a decision for allocation or deallocation of funding requires a discrete budgeting-level framework. By discrete, we mean that if a particular program can satisfactorily accomplish an acceptable number of its goals with reduced funding, the specific level of reduced funding must be identified and defined for that program. In this way, a multiple alternatives decisioning model for evaluating programs for fiscal roll-back can also assess a limited number of discrete levels of funding for any particular program. Therefore, program 'A' at full funding exhibits various measures of performance on such pertinent criteria as effectiveness and efficiency, as well as expenditure level. If it is ascertained that a certain part of A could be omitted from program implementation without significantly compromising A's worth, then it is reasonable to evaluate 'AX' along with A as *two* entirely separate feasible alternatives. That is, 'AX' will also exhibit its own measures of effectiveness and efficiency, with a reduced criterion measure for required expenditure level.

A note of caution and clarification is necessary here. The authors, accepting the discrete level of funding in modeling funding differences, thereby *reject* the closely related idea of partial funding via percent reduction. It is impossible to ascertain the effect upon a program of an intended 12 percent cut in allocation, unless the dollars associated with the 12 percent are identified specifically within the program. The act of "divoting-up" (sic) the reduction across all shares equally is both unreasonable and irrational (but we choose not to overstate our case).

## Building the Fiscal Program System

The decisioning framework surrounding funding levels and revenue allocation has often traditionally been related to the concept of system-building. Under this paradigm, no programs exist a priori, and therefore all potential programs compete (though unequally) for some proration of the total available budget. Education became very enamoured with this concept of budgeting, referred to as zero-base budgeting; and many units used the concept during the early 1970's.

The philosophical elegance of a 'zero-base' model is interesting if not intoxicating: requiring each program to revisit its 'roots' and thus 'stand' the challenge from other competitive programs as they support their claims for even increasing levels of projected expenditure. Others believe that the elegance of the model ends with the statement of its philosophy.

Selecting programs for funding (that is, system building) can also be viewed as an assessment procedure for evaluating certain alternative programs to be added to an already on-going system, and thereby provide some degree of enhancement to the system's mission. Under funding crises however, the question is (normally): what do we cut?; not, what do we add? For this reason, the modeling of a fiscal roll-back decision-making process can easily assume the operational characteristics of the zero-base framework; that is, based upon a certain reduced expenditure budget, what reduced number of programs will continue to be funded?; the balance of the currently operating programs (non-selective) to then be discontinued.

## Revising the Fiscal Program System

An alternative to the philosophy of building anew the system in order to indirectly determine cutbacks, is the idea of:

> given the current system of operating programs and their impact/effect upon the system as a whole, what programs can be directly selected for roll-back based upon their modeled performance criteria?

Through the philosophical stance of revision, the overall objective becomes to choose programs for deallocation while minimizing a decreased satisfaction of required/desired system goals, etc. In the case of fiscal roll-backs, a revision approach is the preferred procedure, though in a modified sense.

Since many educational systems are so large as to have hundreds of model-related programs, it would be very time-consuming to require the modeling of entire systems. An alternative is to model only those alternatives (programs potentially available for cut-back); and to choose from this list of 'feasible' expendable programs for solving the fiscal roll-back issue.

From a modeling protocol, the role of constraints in guiding the fiscal roll-back decision may be seen as: minimizing the loss of the contribution to total systems effectiveness and efficiency; while concurrently maximizing the expenditure differential which is destined for roll-back.

## Benefits of Itemized Budgeting and Delineated Programming

As discussed earlier, the use of delineated programming in the form of multiple program versions, with different projections of discrete levels of funding, can be very beneficial in modeling fiscal systems for roll-backs. It was also stated that knowledge of the level of required funding (as a composite measure) was not as useful as a differentiation of the required allocation into specific delineated object areas of expenditure.

The typical educational budget is grouped into a series of expenditure areas (called objects) which pertain to such foci as salaries, benefits, supplies and materials, equipment and capital outlay. In a roll-back decision, it is reasonable that the decision-maker may desire to constrain some area (object) of funding greater than another. For example, the reduction in the amount of a floated bond issue may require cut-backs, such that the 'capital expenditure object' must be more severely constrained than other areas of object expenditure. Obviously, the administrator cannot allow programs to be implemented if a capital outlay is mandatory, to the success of these programs, with no capital monies available.

Often times the decision-maker may wish to segregate those programs which exceed the 'average expenditure level' from the remaining programs for more detailed scrutiny. Such an evaluation could easily be a useful strategy immediately preceding a full fiscal study of the current operating system. Finally, the impact upon the system of proposed roll-backs determined by a multiple alternatives modeling technique, can only be viewed via the individual expenditure categories if and only if the individual categories were originally modeled.

## Testing for Strengths, Weaknesses and Responsiveness to Stated Needs

Prior to our eminent discussion of the cost/benefit modeling framework as a historical forerunner to the more powerful operations research technique we call the multiple alternatives model, it is advisable that the rationale underlying our preceding comments be reiterated.

Fiscal funding crises require (normally) some degree of expenditure cut-back; it has been the theme of this paper that such decisions should be program-wholistically oriented as compared to leveling a certain "equitable" percentage share across all programs. In other words, it may be more rational to discontinue an entire specific program, as compared to under-funding several of the generic program's specific entries. To operationalize this philosophy, all programs are viewed as multiple alternatives to a fiscal roll-back decision; and measured criteria are used (as contraints) to evaluate all potential combinations and permutations of these alternatives, to determine how many programs must be cut; and which ones. Discrete levels of funding in order to determine various delineated programming alternatives has been discussed as a recommended procedure.

The rationale in the preceding sections has been presented in order to introduce a particular philosophy; and that philosophy reflects the necessity of testing for the comparable strengths and weaknesses between and among program deallocation alternatives; and to specifically determine (understand) each program's (or group of programs) responsiveness to expressed needs of the problem originally intended for remediation. In short, to know what a program is doing and how, and to be able to state why that particular program (selected via evaluation modeling) was 'rolled-back'. Such are the ingredients of a data-based, accountable decision.

# TRADITIONAL MODELING VIA COST ANALYTICAL DESIGN

The plethora of cost analytical frameworks has focused mainly upon four specific evaluative or modeling designs: cost-benefit, cost-effectiveness, cost-utility and (though hardly an analytical framework, per se) cost-feasibility analyses. Some of these models support the use of multiple criteria related to a single focus, while other models prefer a singular criterion formed via the composite of multiple foci; but all models agree upon at least one postulate:

> The analysis (and subsequent selection) of an alternative course of action from among multiple alternatives; subject to the evaluation of each of the alternatives across multiple (or singular) criteria, which are purported to measure the alternative's impact upon the system (of decisioning) being modeled;

and such that:

(1) positive effects to the system are maximized;
(2) negative effects (as by-products) are minimized; and
(3) neutral effects (as desireable) are maintained at the central tendency of measured impact.

To accomplish this end-result, cost-analysis modeling has developed into a science of graphic displays, measurement schemes, and statistical overlays. To date, however, the serious shortcoming of many of the cost-analytical designs has been the model's inability to adequately control for interactive effects between (and among) criteria for any particular alternative being evaluated; and an inherent unreliability to systemically evaluate

Figure 3 Standard Decision Matrix for Criterion-Referenced Analysis of Multiple Alternatives.

Multiple alternatives being analyzed.

| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ |
|---|---|---|---|---|---|---|---|---|
| Criteria #01 | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ | $a_{15}$ | $a_{16}$ | $a_{17}$ | $a_{18}$ |
| Criteria #02 | $a_{21}$ | $a_{22}$ | $a_{23}$ | $a_{24}$ | $a_{25}$ | $a_{26}$ | $a_{27}$ | $a_{28}$ |
| Criteria #03 | $a_{31}$ | $a_{32}$ | $a_{33}$ | $a_{34}$ | $a_{35}$ | $a_{36}$ | $a_{37}$ | $a_{38}$ |
| Criteria #04 | $a_{41}$ | $a_{42}$ | $a_{43}$ | $a_{44}$ | $a_{45}$ | $a_{46}$ | $a_{47}$ | $a_{48}$ |
| Criteria #05 | $a_{51}$ | $a_{52}$ | $a_{53}$ | $a_{54}$ | $a_{55}$ | $a_{56}$ | $a_{57}$ | $a_{58}$ |

a multiple alternatives solution (where the selection of more than one alternative is necessary to adequately satisfy the required demands/needs of the system being modeled). Before solving this difficult problem of multiple solutions across multiple criteria, the reader must first grasp the more traditional aspects of cost-analysis design and modeling.

## Application of a Decisioning Matrix

The choice of a solution from among multiple alternatives, via the evaluation of each alternative across multiple criteria, is easily viewed in a decisioning matrix format <Figure 3>. With each column representing the values of stated criteria for a particular alternative, a m X n matrix is formed; consisting of m-criteria (measures) across each of n-alternatives (defined). And as a 5x8 matrix yields (5)(8)=40 cells, so does a m X n matrix yield (m)(n)=mn measures for evaluation. It remains these mn measures which will then be utilized by the decision-maker to judge which alternative action(s) is (are) the 'best' solution(s) to the problem being modeled.

The decisioning matrix provides a useful formulation for the eventual modeling of the fiscal roll-back context. Defining each of the various alternatives ($A_j$, j=1, ...,8) displayed in Figure 1 as potential programs to be rolled-back in a deallocation decision, the objective becomes: to select that particular alternative ($A_j$) which best exemplifies the stated criteria being used to make the deallocation decision; and which subsequently balances the budget. In reality of course the experienced practitioner realizes that more than a single alternative program may require roll-back if the criterion objectives are to be met. For the purposes of instruction and illustration of the argument however, only a single-alternative context will be illustrated.

The multiple-alternatives context will be discussed in a later section. (Your patience will be rewarded.)

For each alternative $A_j$, then, there exists a series (column) of criterion measures, $a_{ij}$ $(i = 1\ldots,5)$, reflecting the "nature(s)" of the alternative as measured by each of the i-criteria. In the selection of a single alternative, the problem involves comparing the valid $a_{ij}$ measures in a reliable fashion, such that the "character" of each of the particular alternatives being modeled is understood; and thus a reasonable, rational and informed decision may be made (or at least "sophisticatedly guessed at"). To accomplish this analysis of the criterion impact via each alternative upon the system, a specific procedure must be devised.

## The Composite Variable Ranking (CVR) Procedure

The reliable application of any procedure to the evaluation of alternative action access multiple competing criteria, must satisfy at least four primary requisites:

(1) The comparison (evaluation) of multiple criteria for each alternative, requires a single composite value representing each particular alternative be computed from the available criterion estimates;

(2) The computation of a single composite value requires all of the available criterion estimates be rescaled to a common measurement format, both in terms of units (e.g. dollars, square feet, number of pupils) as well as scaling (nominal, ordinal interval, ratio) -- that is, so that apples can be compared to oranges;

(3) The evaluation of the impact upon the system from the criteria being used, requires a method for analyzing the criterion impact across all alternatives (as well as the value of each alternative across all criteria); and finally,

(4) The realistic modeling of a decisioning context, requires the ability to "weigh" the various criteria being utilized, and thereby vary the relative importance of the criterion effect upon the decision(s) being made (alternative choices).

The Composite Variable Ranking (CVR) model has been designed to specifically address these four requirements. After the initial measurement of the criterion variables has been accomplished (e.g. cost of programs parts in 'dollars'; space requirements in 'square feet' or 'number of rooms'; personnel in total 'FTEs'; etc.), the normalized T-scores of the relative raw measures are computed for each criterion variable (across the range of measured alternatives). That is,

$$a_{ij},\ j = 1,\ldots,n \quad \overset{(i,j)}{\overline{\hspace{2cm}}} \quad T_{ij},\ j = 1,\ldots,n$$

for each criterion $i=1,\ldots,m$. This conversion replaces all raw measures (square feet, dollars, etc.) with its associated distributional T-normal. T-normals by definition have a mean of 50.0 and a standard deviation of 10.0. Thus, a facility-space measure of 2560 square feet for program alternative C has a T-measure of 50.0 if 2560 square feet is also the distributional mean across all programs for space requirements. Likewise, a personnel requirement of 12 teacher aides has the T-value of 50.0 if 12 (TAs) is the distributional mean across all programs.

The composite variable ranking procedure summates each column's row entries (that is, adds the criterion T-measures for each alternative), producing a single composite measure per each alternative being evaluated. These T-normal sums can then be ranked such that their ordinally-comparative importance to the decision be recognized.

Likewise, the rows can be summed (i.e., adding across each row's column entries), to understand the relative impact of each criterion across all alternatives within the system. Finally, standard weighting practices can be applied to the criterion T-normals (after normalization, of course) before the summation of the column vector entries.

The CVR modeling technique is an excellent field-tested and validated technique for performing most decision analyses involving decison matrixes. Moreover, the CVR approach is well-defined and easily constructed for a fiscal program alternative's setting. The technique is not without its inherent inadequacies, however, centering mostly around its predominant reliance upon both a singular alternative context and main-effects modeling.

## Main Effects Modeling

In an earlier section of this report, the issue of multiple alternatives modeling (MAM) was discussed in the context of a solution requiring not just one alternative, but rather a finite group of alternatives (referred to as the "alternatives-mix set" in the first topic of the next section). If a decisioning model purports to truly simulate a real situation, then the model must be able to compare groups of alternatives against other groups of alternatives, utilizing the criterion measures which have been selected to simulate the impact of the alternatives upon the

Figure 2. Representation of the Composite Variable Ranking (CVR) Formulization for Main-Effects Modeling.

|  | Potential Alternatives |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Criteria | A | B | C | D | E |  |
| #1 | (1) | (2) → | (5) | (3) | (2) |  |
| #2 | (3) | (4) → | (2) | (1) | (2) |  |
| #3 | (1) | (2) → | (4) | (3) | (2) |  |
|  | 5 | (8) → | (11) | 7 | 6 | (column sums) |
|  | 5 | 2 | 1 | 3 | 4 | (ranks) |

system being modeled. This is the main operational difference between singular and multiple alternatives modeling -- that several alternatives may require operatonalization to satisfactorily remediate the identified problem.

Main effects modeling is a correlated idea to the multiple alternatives context, from the standpoint of the multiple-criterion effect via each evaluated alternative. Consider the following example. Five alternatives have been identified as potential remedial actions for a particular problem being modeled. Each alternative was measured across each of three criteria to permit a criterion-referenced evaluation. (To save time, and wear-and-tear on the authors, the transformation to T-normals is suspended for this discussion). The measurement scale chosen was a 5-point scale with interval of 1 unit, signifying low benefit (=1) to high benefit (=5). The simplified decision matrix is shown in <Figure 4>.

Note that the column sums indicate Alternative-C as a clear 'winner' in this "identify the most beneficial alternative" contest. However, also note that although C's sum was the highest, the measure of criteria #2 for C (=2) suggests C demonstrates moderately-low performance benefit on this criterion measure. If we approach this simulated example from a 'multiple alternatives' vantage, a likely solution might be the incorporation of both C and B into an alternatives mix-set. Note how B's measure of moderately-high benefit (=4) on criterion #2 counteracts C's moderately-low (=2) value. Also, note how C must then make up for B's apparent disadvantage regarding criteria #1 and #3.

Main-effects modeling would have computed the columnar summations, and selected the alternative 'C' as the most-likely solution. It is just as likely that in a more complicated simulation, the decision-maker might not recognize the criterion #2 influence of alternative C. Clearly, this situation is a potential problem with both singular and multiple alternatives modeling simulations.

The solution is to perform what the authors call "interactive effects" modeling -- controlling not only for the presence of multiple solutions, but also controlling for the potential of sub-optimal criterion measures for a given alternative which may be masked by the values of other highly-beneficial criterion measures. The illustration and application of just such a model, the Multiple Alternatives Model, within a fiscal roll-back context is the subject of this report.

## Generic Criteria for Competing Alternatives

We have spent a great deal of energy thus far in describing what to do, how and why ... but have gingerly maneuvered around the question of 'with what' viz. criteria. Criteria must be both system-specific as well as alternative(s)-specific. Roughly translated, criterion measures must reflect both the system being modeled as well as the alternative solutions being evaluated, respectively. Otherwise, the impact to the system cannot be measured, since it had not been modeled (i.e. simulated).

The evaluation of potential budgeting roll-backs is no exception. Criteria must be introduced, measured and analyzed across all alternatives, such that: the alternatives can be validly compared within a budgeting context; and the impact to the system of each alternative (or combinatorial premutation of all available alternatives) can be analyzed. Finally, criteria must be collectively exhaustive of the 'foci' required to criterion-model the decisioning context; and allow cross-comparisons between criterion measures, in order to check for collectively unacceptable 'impact' values (interactive effects modeling).

Modeling alternatives within the fiscal domain represents as clear an illustration of criterion considerations as any multiple-alternatives decisioning situation. For traditional cost analytical studies, the generic focus of expenditure has been the province of cost-benefit analysis. Similarly, foci of effectiveness and satisfaction have remained strong criterion entries in cost-effectiveness and cost-utility analyses, respectively. An additional measure focus of efficiency could find itself in either of the three cost-analysis models, depending upon its source of data (as is probably true for all of the initial three criterion foci).

Nevertheless, these four generic criterion foci (effectiveness, efficiency, satisfaction and expenditure) are directly applicable to the fiscal modeling domain:

Effectiveness

1. How effective are each of the various alternative programs in promoting the district's generic program goals?

2. How effective are each of the variuous alternative programs in optimally reducing the current problems associated with each of the districts' school's specific program goals?

## Efficiency

1. How efficient are each of the various alternative programs in conducting the required instructional programs of the district?

2. How efficient are each of the various alternative programs in remediating the current problem(s) to be solved within the district?

## Satisfaction

1. How satisfactory are each of the various alternative programs in their execution, based upon the distributional domains of the administrator, teacher, student, parent and school board?

2. How satisfactory are each of the various alternative programs in their remediation of the identified problem(s), based upon the distributional domains of the amdinistrator, teacher, student, parent and school board?

## Expenditure

1. What are the specific object costs to the district for each of the various alternatives; and therefore their savings if rolled-back?

2. What are the costs to the district in terms of benefits if the programs continue?

3. What are the costs to the district in terms of 'loss' if the programs are rolled-back?

It is likely (if not strongly suggested) that several criteria (measurement variables) would be identified to adequately model the rather general idea expressed above. For example, the criterion focus of efficiency for a particular set of alternatives curriculum programs might be measured in terms of:

(1) Amount of time in minutes the program requires for instrumentation each week;

(2) Number of students that could be handled per class session (to identify small v. medium v. large group sessions); and/or

(3) Percent of time the program requires use of a particular laboratory or library resource room.

Expenditure is another criterion focus particularly susceptible to the 'delineation' of its content. For example, the total cost of a program is important; but potentially more important is the program's budget-breakdown by object expenditure (e.g. amount for salaries v. amount required for capital improvement). <Figure 5> illustrates the impact of differentiated criterion foci upon one traditional decision matrix.

It may now be trivial to state that each of the four submatrices within the total decision matrix could be itself a decison sub-matrix. Thus the a x n effectiveness sub-matrix could be executed to determine which alternatives best 'fit' one stated effectiveness criteria. In turn, the bxn efficiency sub-matrix could be executed for its solution; and then each of the remaining c x n satisfaction and d x n expenditure sub-matrices could be evaluated. Such a serial procedure would yield four sets of answers (alternative solutions), which themselves would

Figure 3. Representation of a Generic-Criterion Decisioning Model for Analyzing Multiple Competing Alternatives.

| Criterion | Foci | Multiple Alternatives<br>$A_1$ $A_2$ $A_3$ $A_4$ . . . $A_n$ |
|---|---|---|
| (Effectiveness Criteria) | | a x n sub-matrix<br>effectiveness measures across alternatives |
| $\text{CRIT}_1$ | EFFEC-1 | |
| $\text{CRIT}_2$ | EFFEC-2 | |
| . | . | |
| . | . | |
| . | . | |
| $\text{CRIT}_a$ | EFFEC-a | |
| (Efficiency Criteria) | | b x n sub-matrix<br>effectiveness measures across alternatives |
| $\text{CRIT}_{a+1}$ | EFFIC-1 | |
| $\text{CRIT}_{a+2}$ | EFFIC-2 | |
| . | . | |
| . | . | |
| . | . | |
| $\text{CRIT}_{a+b}$ | EFFIC-b | |
| (Satisfaction Criteria) | | c x n sub-matrix<br>satisfaction measures across alternatives |
| $\text{CRIT}_{a+b+1}$ | SATIS-1 | |
| $\text{CRIT}_{a+b+2}$ | SATIS-2 | |
| . | . | |
| . | . | |
| . | . | |
| $\text{CRIT}_{a+b+c}$ | SATIS-C | |
| (Expenditure Criteria) | | d x n sub-matrix<br>expenditure increases across alternatives |
| $\text{CRIT}_{a+b+c+1}$ | EXPEN-1 | |
| $\text{CRIT}_{a+b+c+2}$ | EXPEN-2 | |
| . | . | |
| . | . | |
| . | . | |
| $\text{CRIT}_{a+b+c+d}$ | EXPEN-d | |

require comparison for a final solution. The question arises, "Is this really the best, most valid (and reliable) process to follow?"

Hopefully it is also trivial (?) to the reader, that the full decision matrix (a+b+c+d) x n could have been evaluated; the solutions determined, reflecting those alternatives which best fit the total effectiveness, efficiency, satisfaction and expenditure criterion sets, simultaneously; and thus, optimally operationalize the preferred interactive effects modeling framework as previously discussed.

## A Preference/Trade-Off Analytical Framework

The importance of variable criterion characteristics for a given alternative must be reiterated. Solutions to real-life problems are found to be "perfect" only in textbooks, professor's lecture notes, and the 1950's cinema. In reality, all potential alternative solutions will be found to have at least one flaw (if not many); and still be the best alternative(s) solution available.

In selecting a final alternative as a solution based upon that same alternative's merits, the decision-maker also (consciously, we hope) accepts that same alternative's lack of merit on other less virtuous criterion measures. Recall the illustration in <Figure 4>. Alternative C was selected based upon the merits of criteria #1 and #3. To fill the gap indicated by criteria #2, a multiple alternatives mix-set solution was sought with the subsequent addition of 'B' to the solution set. However had we not the option to choose a set of solution alternatives, would we have retained alternative 'C'. At this level of macroanalysis, the answer is probably 'yes'.

This is the theory of preference/trade-off in alternatives modeling -- singular or multiple. Alternative C was the final choice due to one preference for high benefit on criteria #1 and #3; and a concurrent willingness to trade-off (i.e. accept the negative) the low benefit effect associated with criterion #2. This concept is most important in the understanding of the multiple-alternatives/ interactive-effects modeling technique to be illustrated in Part II of this report; and applied to the fiscal roll-back problem in Part III. The main difference between the way the concept of preference/tradeoff has been described, and the way in which it is actually applied will be evident. Basically, the multiple alternatives model (MAM) will define preference/trade-off as a willingess to accept a central-tendency solution mix-set, where the required impact is not alternative-specific, but rather is mix-set generalized. The measures of central tendency and variablility (distributional mean and standard deviation) will be applied to a yet-to-be-discussed marvelous vector of values called the conditional vector, in order to assume their preference/trade-off flexibility.

# SCHOOL CLOSURES AS A FISCAL BUDGETING DECISION

Few decision modeling situations exist without some amount of reliance upon selected criteria which define monetary items. Indeed, it could be said, that all decisions involve potential changes within expenditure categories based upon the alternatives selected; that is, expenditures will either increase, decrease or remain the same, while revenues are increasing, decreasing or likewise constant. This may seem like 'overstating the obvious case', yet many decisioners often seem determined to study those criterion items concerned with need, demand and performance -- and relegate to final stage, a decision as to whether the selected alternatives can be funded or not within the existing budgtary limits; or whether the newly-decided roll-back in programs will satisfy the reduced expenditure level sought.

In another sense, concern with the fiscal portion of problem resolution may in fact signal the reasonableness of a particular policy decision; and the likeliness of a particular policy alternative in resolving a problem issue. In today's educational climate, decreased revenues for instruction, salaries and building maintenance have announced the era for the closing of schools as a cost savings stratagem. Opponents of a school closure policy attack such an solution alternative as not cost-effective in terms of expenditure savings, and not cost-benefit in terms of potential decrease in educational quality. The author has explored this issue, and presents the following as an illustration of utilizing fiscal criteria in determining an initial policy standard -- prior to developing the various multiple 'implementation alternatives' which would execute the policy, and its implications.

## Cost-Benefit and School Closures

A selected alternative is viable and feasible only insofar as its effectiveness in remediating a particular stated problem is conclusively defined (Wholeben, 1980a). Within a competing situation such as that brought about by declining school enrollments, increased public demand for program management accountability, spiraling inflation, and economic recession -- solution alternatives such as school closures and attendance zone consolidations for reducing expenditure levels must not only reduce or eliminate the negative biases of the defined problem, but also promote positively-related benefits as well.

Issues of cost-benefit and program effectiveness within the educational sector define three major target areas for the evaluator's focus: (1) level of plant utilization, (2) degree of curriculum accountability, and (3) extent of staffing requirements. Each of these three issues concerns an independent though related aspect of educational consumership and management. The decision of the policy analyst to select school closures as a means of abating the negative influences caused by declining educational consumers, must carry with it the concomitant increase in those positive-criterion references at remaining operational sites, in order for a closure policy to be a viable alternative.

## Physical Plant Utilization and Related Fiscal Resource Allocation

School sites maintain certain fixed costs and/or overhead operating expenditures, unrelated to the level of educational operation. Such requirements as heating, air-conditioning, lighting, maintenance, principle and interest payments on bonds, and grounds maintenance are the more immediate issues of fiscal demand that are not fully explained by the degree of building use. Given some agree upon criterion measure of cost-benefit (e.g. heating therms per student enrolled; or maintenance requirement per existing vacancy status) proportionally greater energy and fiscal resources are consumer for less operational occupancy.

Physical utilization of premises and the costs associated with utility are the simplest to measure for criterion generation. Independent of the remaining issues of program implementation and staffing, the importance fiscal overhead is generally not understood by the community-at-large. Criterion measures as energy therms per square foot, and available instructional space per enrolled student at maximum enrollment potential -- are clouded by notions of "less class size equals better education", and "less site enrollment equals less on-site maintenance expenditure". Unfortunately, such ideas lack empirical substance.

Examining specifically the probable bases for these views, it has been found that in a school district of 32 elementary schools:

> the level of enrollment explains less than 13.7 percent of the variance associated with maintenance expenditures; and less than 27.0 percent of the variance associated with total utility expenditures;

but that:

> site area explained 63.6 percent of associated heating requirements, 47.5 percent of related utility expenditures, and 40.6 percent of total service (maintenance plus repair and replacement) costs (Wholeben, 1980a).

Such findings would suggest, that fixed costs exist at a relatively constant level, regardless of building utilization. It necessarily follows, that the more such costs are distributed across reduced sites, the lesser the level of total expenditure.

## Curriculum Program Flexibility and Related Cost-Benefit Indicators

Not as easily quantifiable yet no less reliable are the trade-offs associated with specialized curriculum programs (i.e. those requiring specially trained personnel) and fiscal allotments.

Even if (only) a single student requires specialized assistance -- that assistance must be forthcoming. Special programs require special people (normally with more specialized training), and therefore at greater cost. Certainly, it may require a person who will deal more individually with the student's needs. Thus, the issues are: a higher paid person to deal with a smaller assortment of specialized needs; and an individual person dealing with a smaller number of students -- an individual who might otherwise have been instructing a 'regular' class -- and thereby negating additional staffing requirements.

Many specialized classes exist based upon demonstrated need (e.g. bilingual), demand (e.g. handicapped), and desire (availability of assorted monies and grants). Oftentimes, the degree of support is based upon the degree of need; for example, an enrollment of 10 pupils may recieve greater funding as compared to a situation with 5 students. While funding may be contingent upon enrollment, expenditures often are not. The difference between allotment and need must be borne locally if the program is to survive. Nowhere is this more demonstrative, than as realized by the legislated requirements of P.L. 91-941, and the reduction in federal funds to help local districts satisfy these demands.

Three alternative solutions to this situation would seem to be:

1. specialized teachers at particular locations with additional duties assigned to teachers;
2. specialized teachers at particular locations with student collectively transported; and
3. itinerant teachers serving several locations.

Unfortunately, negative measures (outcomes) associated with under-utilization of talent, scheduling constraints, and wasted transportation time and expense, militate against the final use of such remediation strategies.

Program consolidation at operating schools after selected site closures will servie to alleviate these dilemma. Less programmatic personnel will be required as well as a more efficient distribution of "utilization per overhead" affected. Specially trained personnel will be utilized more efficiently, transportation and time costs reduced, and external funding (as available) more efficiently allocated.

## General Program Staff Requirements and Related Cost-Efficiency

The final issue in examining fiscal expenditure requirements within the policy decision of school site consolidations, lies in the understanding of the distribution of salary and instructional costs across enrollment. Related to the physical plant and curriculum issues, general staffing interests are nonetheless unique in that no inference is directed towards quality (i.e. only quantity is of concern).

Salaried teaching personnel gain no additional remuneration if they instruct more students than another teacher within the same district; and teacher-management contractual guidelines are in force. The elementary school teacher is provided the same salary whether in an under-utilized or crowded school setting. Very simply, with a ratio of 20:1 as specified by contract, four teachers with 15:1 classrooms could be replaced with three individuals with the contracted 20:1 assignments. Thus, the union of 'class consolidation' with 'site consolidation' provides a clear conceptual context for cost-benefit savings.

## Regardless of the Savings ...

The above three issues of plant utilization, curriculum accountability, and staffing requirements support the potential of using school closures as one alternative to a simultaneously declining student population and fiscal revenue milieu. Taken singularyly or collectively, it is emphasized, that they are not the sole grounds for effectuating a consolidation strategy -- only that fiscal improvement and expenditure relief are possible. And the author concedes as equally important a criterion, the question:

> "How much improvement is worth closing a school?"

As will be presented in a later chapter via an elaboration upon use of the decisioning model SCHCLO (the SCHool CLOsure model), a framework does exist for evaluating and contrasting criterion references in order to target potential closure sites. It is further maintained, that modeling neither emphasizes nor de-emphasizes any particular societal value or morality -- in the technical sense, that is. Rather, such often qualitative data must be weighed by the decision-maker, subsequent to receiving the modeled evaluation output and results.

# CHAPTER 03

# THE PLANNING STAGE

## [ Examining Basic Issues in Field Applications ]

## THE ISSUES

The construction of a decisioning (sic) model requires, that initially within the planning stage of such formulation a clear understanding exist between the theoretical constructs of the model, and its design in satisfying these constructs. Or in the more proverbial sense, 'know where you are to go, and how you intend upon getting there -- before taking the first step'. The planning for modeling formulation is very much a stepwise, sequential process, not only in terms its actual, physical construction, but also in light of the numerous theoretical bases which underlie and guide that construction. This chapter serves to highlight these preparatory guidelines; and to further serve as a 'field applications' primer for the novice -- to illustrate the fundamental linkages between the use of "multiple alternatives analysis' and the 'multiple alternatives model' -- and provide a solid base for understanding the relationships between the theoretical constructs (i.e. issues) on the one hand, and their pragmatic implementation (i.e. applications) on the other.

Chapter three will utilize the "issue v. application" paradigm as an instructional technique in presenting the major issues which guide the design and construction of the multiple alternatives model, and its ultimate utility in determining multiple alternative solutions. Four general topics will be addressed within this chapter:

Initial Constructs for Understanding;

Inter-relationship of Multiple Alternatives
with Competing Criterion-References;

Design Contingencies for Model Building; and

Control Contingencies for Model Execution.

These general topical areas will be discussed via nine specific issues, and the illustrative field applications which demonstrate each issues' pragmatic base within educational evaluation and decision-making.

The first general topic concerning 'initial constructs' will examine the initial foundation (and its critics) for the modeling of policy alternatives, and the difference between policy and action-alternatives' modeling. The second section concerning 'alternatives and criteria' will illustrate the use of single and multiple entry modeling, and the comparative differences between main and interactive effects formulations.

The third part of this chapter attempts to define the relative importance of two major constructs in model planning and design, that the model exhibit degrees of both mutual-exclusiveness and collective-exhaustiveness in its construction. Finally, the area of 'control contingencies' will be highlighted via a discussion of measureable system impact, decisioning optimization, and the acceptance of preferences and trade-offs.

While chapter two sought to place the use of multiple alternatives analysis within a specific context for the initial understanding of the reader -- the context of program budgeting and fiscal roll-backs -- chapter three now commences the more theoretical education of the reader, and presents a discussion of nine issues (with their applications) necessary for a more thorough understanding. Chapters two and three provide a prelude to the content of chapter four which discusses the more technical and mechanical rudiments of the multiple alternatives modeling framework.

# MODELING POLICY ALTERNATIVES

All decision-making represents a conscious and demonstrative selection of one or more choices of 'preferred' action, from a multiplicity of alternatives -- be they "policy" alternatives which define the policy in approaching a specified problem area, or "action" alternatives, methods of following the defined policy and thereby implementing its guidelines. Policy modeling more-over, requires a strict belief on the part of the modeler that: first, responsible decisioning demands the need to project the future impact of alternative decisions prior to their selection and execution; and second, accountable evaluation of these various alternatives demonstrate that which we understand and know of the effects of today's decisions, and their utility for simulating tomorror's decisional requirements. This is a true exposition of the 'pragmatic research' and 'utilization-based evaluation' which is required of every emerging educator in today's ever-changing world.

## The Issue

The realistic cynic involved in policy evaluation would define the environment of policy implementation as one wherein, "to do one's able best, within what one is enabled to do." The analyst would attest to the 'able' as defining the degree of intelligence or knowledge the policy implementator brings to the execution of the role; and to the 'enabled' as specifying the constraints implaced by the environment upon the successful implementation of the policy guidelines. Indeed, policy is but a set of guidelines for assisting the administrator in eventually obtaining satisfactory completion of both personal and organiza-tional objectives.

Figure 6. Stratification of Operations Research (OR) Applications Within Educationally-Related Environments.

LIBRARY OPERATIONS

TEACHER ASSIGNMENT
PERSONNEL SELECTION
GRADUATE STUDENT SELECTION
STUDENT ASSIGNMENT

FACILITIES LOCATION
SCHOOL SITE PLANNING/CONSTRUCTION

CAI COMPARISON
EDUCATIONAL ADMINISTRATOR PREPARATION
COUNSELOR TRAINING
CURRICULUM REVISION
TEACHER TRAINING

VOCATIONAL EDUCATION/REHABILITATION
HANDICAPPED/DISADVANTAGED
WORK ENVIRONMENT/PRODUCTIVITY
MANPOWER TRAINING
RELOCATING THE UNEMPLOYED

STUDENT BUSING
URBAN MASS TRANSPORTATION

CORRECTIONS
INCARCERATION v. PROBATION

ENVIRONMENTAL POLLUTION
CHILD DAYCARE
DEPLOYING EMERGENCY SERVICES
STUDENT HEALTH SERVICES
FOOD SERVICES
OUTDOOR RECREATION

DESEGREGATION

AUDIO-VISUAL/MEDIA

INSTRUCTIONAL EFFECTIVENESS
ACCOUNTABILITY
ORGANIZATIONAL COMMUNICATIONS STRUCTURE

ENROLLMENT PROJECTION
CURRICULUM TIME BLOCK ASSIGNMENTS

STUDENT MAJOR v. COURSE SELECTION

Policy is itself of course, an alternative course of action which has been agreed upon by the leaders of the organization involved. It defines a set of strategies or over-riding dogma within which the organization must operate; and from which more specific tactics or performance specifications will evolve. The idea of "modeling" is borrowed from the engineering scientist, and represents a belief that careful study and investigation of 'observed' phenomena will aide the careful decision-maker in understanding potential 'expected' phenomenon-impact based upon upcoming decisions. That is, the policy maker needs some sense of what impact will accrue to the system as a whole, based upon the implementation of different decisions. The sufficient outcome of 'modeling policy alternatives' illustrates then for the decisioner, what differential benefit exists for the system as a result of differing policies, and their varying effects; and therefore matches for the system, the decisions of today with the desired effects of the future.

The general idea of policy alternatives' modeling however suggests at least three different perspectives to be addressed. First, such modeling can imply the need for modeling alternative policies; that is, to study the philosophies associated with each of several alternative policies, and therefore to decide ultimately upon which philosophy will be defined as directing future organizational efforts. Secondly, policy alternatives' modeling might also suggest the highly structured modeling of the potential 'action alternatives' illustrative of a decided-upon statement of policy or philosophy; that is, what actions are now possible based upon the philosphy or policy adopted, and furthermore, how do these actions now differentially provide the desired impact(s) to the system as a whole. Finally, the modeling of policy alternatives might well address the fundamental need for the policy analyst to model the various 'contingency outcomes' for the potential alternative actions now implementable based upon the philosophy or policy adopted.

The first idea of modeling parallels the input portion of evaluation modeling: What ingredients will be entered into the organizational framework in order to produce the desired effect? The second idea best illustrates the process portion in evaluative simulation: What procedures or particular decisions will result from the stated philosophy in order to satisfy the identified needs and demands of the system being modeled? The third notion then specifies the output portion of modeling: What results will be incurred based upon the various specific actions taken as a result of the particular policy adopted? How the decision modeler proceeds with the process of 'modeling policy alternatives', will largely depend upon which of the three levels of specificity stated above, best illustrate the declared direction of the investigation to follow.

## The Application

There once existed three rather large and prosperous school districts who began to experience parallel problems of declining school enrollments and dwindling fiscal budgets. The first school district assembled their very able policy analysts and evaluators, and decided that environmental impact statements were needed to support the district's a priori decisions as to which school to close -- noting that this district had already decided upon school closure as the policy decision to adopt. The criterion of 'attendance zones' and its relation to student population centers represented the major (or sole) criterion for deciding which site was to be released from the roles. The second school district realized, that more than a single criterion would be necessary to decide which school (or schools) should be closed, and so they also assembled a committee. However, this committee was comprised of community individuals from each of four sections of the district which most likely would have to release a school site, and consisted of such membership as businessmen, housewives and various blue-collar workers. To demonstrate true community involvement, the superintendent charged this group with two directions -- the first, to determine a set of criteria which would then be utilized to evaluate each of the school sites for potential closure -- the second, to submit a list of four sites for potential release, based upon the results of this committee-based evaluation.

Our third school district initially studied the need for site closures as a means of alleviating the problems associated with declining enrollment and decreasing school revenue; and found this alternative to be the most likely solution strategy ("policy alternative") to follow. Representatives of the district office, field administrators and classroom teachers, experienced university educators in evaluation and decision-making, and community representatives were assembled to study the problem. A large set of criteria (and their associated criterion-references) were drawn-up, and evaluated for their suitability in determining school closures. Three models were specifically designed to evaluate the criteria, and their impact upon the decision(s) to be made -- how many sites to release, and which ones. And finally, the models executed, the results evaluated post-hoc, and the results released for public scrutiny.

Only one of our three districts had a happy ending. Yet all closed schools as the policy response to declining enrollment and decreased revenue. What existence of differing modeling procedures, or modeling outcomes, served to predict more success for one school district over the others?

Although one modeler was successful, all faced the same problems associated with the fear, disbelief and ignorance of the general population. Nowhere is this better and more clearly witnessed, than in the situation of 'program budgeting cutbacks' as discussed within chapter two. The major problem to be addressed in all modeling episodes is that of criterion definition, referencing and measure.

Criterion definition involves the illumination of those areas which will serve to compare the potential alternatives for inclusion within the solution set. In the problem of budgetary cuts, criteria of need, demand, performance and personal satisfaction are often defined for use in a comparative evaluation. Criterion referencing comes immediately after definition, since once types of criteria are agreed upon, sources of their measure must be denoted in order to gain the evidence decreed by the preliminary definition. Areas of curriculum design and implementation will often have references such as gain scores on standardized batteries to denote (reference) a particular criterion of performance. Thus the results of each student's performance on such a test will provide input to the final selection of one curriculum alternative over another, in the pursuit of instructional excellence. Although last in the series, criterion measurement is often the most volatile, and least defensible for the model builder. The measurement of performance via standardized scores from an achievement battery is seldom questioned, but not equally so for the needed measures of personal satisfaction as might result from responses to several items on a 'disagreement - agreement' continuum.

Individuals not understanding the model's utility, or understanding it well enough to not want its objective evaluation of the alternatives -- will raise such issues as true impact not being measureable, or that true impact can only be measured over several years of observation (not heretofore existent, of course). These critics will declare that competition for scant resources leaves the process open for hidden agenda and perpetrated bias, and that modelers will be able to use jargon and mumble-jumbo to convince others of the validity of the modelers' decisions. The major argument -- and the one most likely to destroy the utility of a decision model for evaluating potential deallocation alternatives for the welfare of the organization -- is one which states, that:

> All program units now existent are essential to the mission of the organization; and therefore elimination or deallocation is an unreasonable decisional alternative. The more prudent course of action is to reduce budgetary allowances by some percentage amount across-the-board, and direct each unit to live-within-their-means.

Such a policy alternative is most likely only because the necessity of such hard decisions such as reduction-in-force of personnel will no longer be necessary from the upper-echelon of the management hierarchy.

There is but one protection against the arbitrary and capricious judgements which the cynics and critics declare as dooms-day heralds; and that is the use of a clear, alternatives-based, criterion-referenced, decisioning model. Such a model must not only be able to evaluate both policy and action altervative decisions, but also do so in a complex environment which controls the worth and desirability of each alternative, its impact upon the problem to be solved, and its collective benefit to the system as a whole.

## POLICY V. ACTION ALTERNATIVES

One can view the policy alternative to be decisioned as the over-riding philosophy or direction which an organization will adopt in determining future, specific remediation strategies for the identified problem situation. Once determined, the specific action alternatives to implement the guidelines of the policy must be evaluated and themselved decisioned. In effect, the action alternatives are the 'degree' of remediation to be offerred to the 'direction' of the policy being followed.

### The Issue

When a decision-maker or policy analyst "models" alternative courses of action, a basic distinction must be made between the level of specificity addressable by the actions defined. Recall that a policy represents a philosophy to be adopted and followed; whereas the actions associated with particular policies represent the implementation fostered by the policy adopted. Therefore, the likely result of policy-level modeling will be the adoption of a singular philosophy, within which the organization will operate. At another level, the philosophy adopted will guide the organization in successfully remediating a particular issue or problem facing the organization at that time. Obviously, different philosophies may be instituted as different times, depending upon the more higher-level or esoteric philosophies of the organization. For policy alternatives therefore, the result of modeling, or the simulation of potential outcomes, would most likely be the choice of a single policy or strategy of action.

The second-level of policy alternatives' modeling however, addresses not the philosophy decision per se', but rather the likely actions which are allowable based upon the specific policy or philosophy adopted. Such *action alternatives* could be singular or plural (i.e. multiple) in scope; but address the implementation of the particular philosophy guiding the organization's efforts. Action alternatives are further distinguished in their implementation for satisfying the defined policy, by whether or not the particular actions project a focused attention upon different aspects of the problem being solved, or different ways of solving the same problem. In either case, the alternatives finally selected for implementation may be singular or plural (i.e. one or more actions taken). A further refinement of the plural case, lies in deciding whether each of the plural decisions require a single-entry or multiple-entry solution.

## The Application

In the management of decline enrollment, and its negative effect upon school district functioning, the wealth of policy alternatives could sustain a planning and evaluation staff for months. The novice often thinks of closure v. no closure as the two alternatives facing the superintendent. However, these are but the tips of the iceberg, as it were.

The complexity associated with the notion of closing a school, leads the decisioner to address the many subsets of such a global policy endorsement. If a site is to be released, will the school be mothballed, leased or sold? If mothballed, how soon will the site be reopened based upon a shift of the enrollment population? If the site is to be leased, who will be prospective leasees? If the site is to sold, what will be the conditions of sale? and will any controls be placed upon the type of buyer?

Of course, the site might be retained for instruction, and other avenues of strategy explored for remediating the negative impact due to declining student enrollments. For example, a variation on the strategy utilized during the enrollment boom days may be employed. That is, conduct classes during a smaller portion of the day (say, the morning hours), release the kiddies before lunch (thereby eliminating associated expenditures), and make the school available to other organizations during the afternoon, during 'normal business hours', and at some fee.

And then there is the situation where the decline of student enrollments may only affect some selected grade-levels, isolated to a particular grading configuration (e.g. K-6, 7-9 and 10-12). The reconfiguration of grade-locations (say to a K-5, 7-8 and 9-12) might also be a most viable alternative in solving several related problems (e.g. vacancies at one site and over-crowding at another).

But then of course, there is the usual policy alternative of doing nothing -- simple to follow, easy to design, and best of all, maintains the status quo.

At the next level from policy alternatives, are the action alternatives to be evaluated to implement the philosophy selected. For site closures, the design of a model for determining action alternatives must of course compare each and every available site for potential closure -- the major decisions being how many(?) and which ones (?). For grading reconfiguration, each and every possible combination of grading sequences must be explored, linked, and crossed-examined. That is, considering the potential alternatives of a K-6,7-9,10-12 sequence, a K-5,7-8,9-12 sequence, and a K-4,5-8,9-12 sequence, not only must the individual segments be analyzed (i.e. K-6 v. K-5 v. K-4) for particular homogeneous curriculum groupings, but so also must total effect over time be addressed as a collective grouping (K-4,5-8,9-12, as an example), in relation to feeder patterns, long-range forecasting and future community planning (new housing starts, multi-family dwellings,etc.).

Like all sequentially-based processes, the choice of a policy alternative must be rigorous and final. Once the policy for dealing with a problem is defined, the full energy of the organization must then be directed towards the design and evaluation of related action alternatives. As will be discussed in the next chapter, policy and action alternatives may both be evaluated as "multiple" in nature, and have the ability to be criterion-referenced and modeled. However, the decision-maker must never lose sight of the need for simulating likely impact from either a policy or action decision -- and in this way, be able to revert posture and change course if an unforeseen negative effect to the system becomes visible.

# SINGLE- V. MULTIPLE-ENTRY SOLUTIONS

The conceptual difference between a closing or not closing a particular school, and the notion of how many will be required for closing, and which ones -- illustrates the common misunderstanding on the part of evaluators and decisioners regarding the potential of modeling in the multiple alternatives environment. No one or single decision exists in isolation from the full spectrum of the organization -- nor from the impact related to other coterminous decisions being made. Communication specialists in their organizational development models during the late 1960's, demanded renewed efforts for increased communication between and among the structure of the organization. No less important is such communication to the design and execution of a criterion-referenced decisioning model within multiple alternatives analysis.

## The Issue

Single-entry actions suggest a 'single' response is satisfactory for addressing a particular issue or problem. This type of alternative is plural in the sense that several 'singular' solutions may be required to provide a one-to-one response to the several problem areas related to the strategic policy involved. What results in the final choice of a particular action then, is one and only one action to be taken in the solution of each particular problem identified. Combinations of single-entry actions or solutions would exist only in as much as the several problems being addressed were in some way related.

Multiple-entry actions or solutions in response to the implementation of adopted policy however, suggest that a combination of actions are required in order to successfuly remediate the problem area involved. Typically, a multiple-entry setting addresses the area of decision modeling, wherein some set of 'all possible decisions' must be analyzed; and the dual decisions of "how many" and "which ones" be finalized. The particular difficulties associated with multiple-entry solution formulation lie within the dynamic relationship between these interactive questions of size and membership. The size of the final solution set (that is, the number of alternative actions required to meet policy objectives) obviously depends upon the choice of actions to become members of that same solution set. The choice of some individual solutions may require a much 'smaller' set of actions necessary for implementation, as related to a smaller set of other actions which will "do the job" just as satisfactorily as the larger-membership set.

The sophistication inherent within multiple-entry solution determination is best understood in the required 'dynamic' power of the selection strategy. Since in effect, all possible combinations and permutations of potential solutions (actions) must be analyzed, a situation of just three potential alternatives might require seven analyses, four alternatives would need 15 evaluations, and five potential solutions a total of 29 assessments. Typical circumstances have been found to easily incorporate 32 possible multiple-entry memberships (Wholeben, 1980a) and 41 potential memberships (Wholeben and Sullivan, 1981). Indeed, it is well within the realm of reasonable imagination that situations of several hundred potential alternatives for multiple-entry comparisons be required. Such estimates increase exponentially as the decisioner considers the number of criterion references being utilized to evaluate both the positive benefits as well as the negative byproducts of the various alternatives, and their combinated potency.

## The Application

Since it is easily accepted in the modeling of schools for potential closure, that the choice of one school could inadvertently 'save' a neighboring school due to the influx of student transfers from the closed site -- the realm of a multiple alternatives, school closure model demonstrates the effect one member of the solution set can have upon another potential member for that same set. The issue of single v. multiple entry solutions is not reserved for the setting of policy v. action alternatives analysis alone. Indeed, a school closure model could result in the closure of one site only, and therefore be an example itself (although not a good one) of a 'defected' single-entry modeling episode.

A better and more utilizable setting for single/multiple issue and its application within decisional modeling, lies within the area of curriculum activity packaging, or general goals/objectives packaging (Wholeben, 1980b). In a overly simplified example, consider the decision to be made between instructing either concept A or concept B -- obviously, a single-entry decision; and let us further assume no other concepts are to be comparatively evaluated. Each concept of course, consists of a number of instructional objectives necessary to bring about the desired level of conceptual learning involved. But of course, each of the multitude of these goals and objectives have also associated with them a series of instructional, classroom (or homework) related activites which if executed, will bring about satisfaction of the goal or objective; and when all goals/objectives are satisfied, the singular concept satisfied as well.

Consider this problem: to determine whether concept A will be implemented to the exclusion of concept B, or vice-versa; and determining which objectives will be utilized to determine such a decision (where not all objectives will be allowed execution); and furthermore, which activities will be utilized to determine which objectives will be executed to determine which concept will be finally decisioned. Complex enough?

While the choice of concepts is obviously a single-entry matter, the potential grouping characteristics of the objectives at one level, and the activities at another level, illustrate the impact lower-ordered multiple-entry decisions will have upon a higher-order single-entry decision. It is not at all trite to state, that one does not decide first the activities, then the objectives, and finally the concept -- for such is the ingredients of an irrelevant and therefore invalid decision. In truth, the model must not evaluate the potential of the activities in various groupings, but also the objectives in various higher-order groupings. Thus, differential objective groupings will hold differential activity groupings, and all potential impacts of all potential combinations (or even permutations) must be evaluated for worth -- exciting, is it not? As we will see in the next section regarding interactive effects, some 'more valued' activities may be discarded due to their inability to 'mix optimally' with other activities.

For a more interesting and not-so-oversimplified example, the discerning reader is directed to the discussion of the decisional model for evaluating computer-assisted/computer-managed instructional objectives across multiple micro-computer hardware and software packages -- arriving at the best instructional package -- in chapter eleven.

## MAIN- V. INTERACTIVE-EFFECTS MODELING

The control of multiple alternatives decision-making is itself, a double-sighted context; that is, choosing between multiple alternatives, evaluated across competing criteria, and choosing between individual and collective criterion impacts, resulting from the various multiple alternatives. Decisional modeling must provide for a strict visibility of criterion impact, both singularly as well as collectively. Without such conscious control, an alternative with high positive criterion measures on a number of variables can arithmetically 'cancel' the negative effect of other variables as the model evaluates the criterion measures.

### The Issue

Modeling as a useful strategy for evaluating the potential benefits and/or shortcomings of a set of different solution alternatives must depend upon the various criteria which have been selected and identified to provide understandable measures of such benefit or loss. While it is easy to understand the competitiveness within the set of potential alternatives to seek membership within the final solution set (defining how many and which ones), it is also as apparent to perceive the parallel competing relationships found within the set of criterion references utilized to measure each alternative's contribution to system impact, and the various combinatorial permutates which result by varying solution set memberships.

The most accepted form for displaying multiple alternative actions across competing criterion references is the decision matrix, where alternative solutions are identified across the top of the matrix as columns, and criteria down the leftside of the same matrix as rows. This simple 2-dimensional design is sufficient for the single-entry case discussed in the previous section. By imposing the possibility of multiple-entry solutions upon the matrix, and further stating that the solution set will comprise a total of k-action alternatives, the matrix becomes a 3-dimensional figure, with height defined by membership. However to take this analogy one step further, the potential of varying membership size forces the addition of a fourth dimension, beyond the visual understanding of the average person. It is in this context of 4-dimensional modeling, that the realm of 'multiple alternatives analysis', and its related dependence upon interactive-effects modeling exist.

To understand interactive-effects, one has to first comprehend its counterpart, main-effects modeling -- and the basal differences between the two. First, it is important to note, that main-effects modeling does not presuppose a single-entry decisioning context only. Main-effects modeling defines a procedure for evaluating potential solutions only in their contribution to a single composite measure of system impact. Each potential action would form a linear combination of stated criterion impact (e.g. add 'positive benefits' and then subtract the 'negative by-products'), and result in a single measure of potential for that particular action's influence in solving the problem at hand. Left relatively uncontrolled, are the effects to the system as a whole of the other potential alternative solutions being considered. In the singular alternatives case, where one and only one solution alternative will be chosen, this is not considered to be a major shortcoming. In the multiple alternatives case however, where the solution set membership (size) is dynamically determined by the strengths and weaknesses associated with the particular combinations and permutations of the alternatives being evaluated, main-effects modeling strategies are a serious compromise to solution validity and modeling reliability.

Interactive-effects modeling satisfies the dual needs for measuring (controlling) both individual and collective contributions of the multiple-entry solution to the defined systemic problem. Not only can the variability introduced by varying solution set memberships and sizes be analyzed and evaluated, but moreover can the dynamic impacts of the identified postive and negative influences to the system as a whole be monitored and controlled. These collective influences to the system, dependent upon the composition of the solution set, allow not only the potential alternative actions to be competitive, but also permit the various criterion references defining impact to be likewise competitive in assuring, that the final solution set membership conforms to the pre-established norms of the policy (philosophy) of the system -- a previous modeling decision.

## The Application

The process of selecting a micro-computer system for a school or district office is not as easy as reading the brochures, and then buying what your neighboring school bought (anyway). The relevant potential of a computer system within the educational environment -- for the full range of administrative, instructional and evaluative data processing options -- is truly infinite.

Consider a situation in which a number of instructional goals have been identified as being most amenable to presentation and drill via a computerized system. Assume also that a number of administrative goals have also been delineated, in which many of the student record keeping, budgetary accounting, and inventory control functions of the main office could be facilitated by some form of data processing system. Clearly, many usable systems do exist on the market ranging from the familiar TRS-80 and APPLE models to the less familiar OSI and HEATH sets. A variety of options exist for each of the particular models or systems; and a equally diverse number of integral peripherals are likewise available to complement and exponentially upgrade any base-format systems. The questions become: how to related the various instructional and curricular components to the various software, and then to the hardware system compatible with the desired and usable software; and, how to design an instructional system totally compatible with the administrative requirements for a database manager.

While chapter 11 deals with this issue in greater specificity, it is appropriate to examine some of the criterion references which might be utilized to perform some a high-level comparative analysis between administrative and instructional objectives, and their appropriate satisfaction through the purchase of related hardware and software.

Generally, it is obvious that some degree of measure will be required concerning such generic criterion references as need, demand, performance, effectiveness, efficiency and satisfaction -- notwithstanding the ultimate criteria, cost and availability. In addition, different views from diverse populations will be required in order to survey and understand opposing opinion structures. Therefore, it is likely that measures of opinion concerning the need, demand, effectiveness, satisfaction, etc. for various items will be forthcoming from administrators, teachers, students, and quite possibly parents as well. In addition, it is further likely, that some items will be arithmetically differenced in order to not only measure the degree of opinion, but also the degree of consistency between potential user groups. Thus, teacher v. student, teacher v. administrator, student v. parent, and so forth must be criterion modeled in order to denote a measure of consistency, or more appropriately, potential future conflict of interest and need.

The seasoned evaluator and decision-maker realizes that no one alternative mix between alternative objectives, hardware and software will be perfectly acceptable to all needs and demands involved. Therefore, a greater degree of closeness between the administrator parent opinions may be seen as important as a high degree of consistency between teacher and student views. Even if the teachers and students do not rate a particular software package in science as the highest in quality -- as long as their measures are at least acceptable, it may be better to choose the package on which their opinions were most alike. However, the combinations of objectives and software match-ups are numerous, and different combinations or permutations will alter the final criterion measure of consistency. To choose the best match of objectives, hardware and software, the model must keep track of the level of consistency (in this example), the limit of consistency required and the minimum of singular acceptability for each software item individually, and of course the membership of the particular grouping which best illustrates the highest degree of consistency possible.

The usefulness of such a model obviously, is in the promulgation of the above control on consistency, while also choosing the best, possible system within district (or building) expenditure limits.

The modeling of interactive-effects is one of the paramount strengths of the multiple alternatives modeling technique. While it will control the selection of any particular alternative based upon that alternative's criterion measures, the model will furthermore control for total impact upon the system, in terms of the full membership of the solution set decisioned.

## MUTUAL-EXCLUSIVENESS IN MODEL PLANNING

In model building, alternatives should be both separate and independent in terms of their identification and definition -- that is, be mutually exclusive of other alternatives. Without this control upon the formulation of alternative courses of action, the comparative evaluation of alternatives would be pitting some alternatives against themselves -- somewhat useless -- but certainly confounding to the measures of the various criteria involved. The pitfalls of non-mutually exclusive criteria -- sometimes known as multi-collinear weighting -- will also provide a bias to the model which may be unintended; or if intended, unprofessional.

### The Issue

The modeling of policy alternatives, whether in the higher-order situation of determining general direction or philosophy or in the lower-order context of determining specific actions in satisfying the determined philosophies, requires attention be given to the degree of distinctiveness or independence between each of the alternatives being evaluated. It is obvious, that the modeling of very similar policies would be a waste of time --assuming of course, that this degree of similarity was acknowledged prior to the evaluation of alternatives. This question of similarity refers to the concept of mutual-exclusivity regarding the construction of alternatives, and the related impact upon the decisioning model.

The idea of economy in modeling alternatives is somewhat innocuous when discussing the similarity between alternative policies or implementation actions. However, the degree of collinearity between criterion references can potentially have a demonstrative effect upon the modeling process, and the solution resulting. For example, if the modeling framework evaluating the alternatives does not control for the existence of multi-collinearity between criteria used in assessing the value of those various alternatives, the potential for "stacking" the model is present -- that is, introducing relative identical criterion-referenced measures and thereby 'weighting' the likelihood of particular alternatives in becoming members of the final solution set. Such weighting of outcome could obviously be by accident, or more importantly, by design.

The concept of mutual-exclusiveness in model planning is thus related to both alternatives construction and criterion reference utilization. Overlap in the design of alternatives provides an unnecessary burden for the model during its subsequent evaluation mode, but is not necessarily compromising to the results of the solution process. The degree of similarity between alternative policies or actions is governed by the desire of the model builder to design a 'clean' representation of the various philosophical or action-oriented alternatives; and by the degree of 'clear' understanding of the problem at hand, in the mind of the model builder. However, overlap with regard to criteria inclusion in the assessment process can be a method for providing high probability of a particular alternative's final membership within the solution set.

## The Application

The modeling of schools for potential closure is a fundamental example of evaluating mutual-exclusive alternatives. Although the fate of some sites may be inextricably linked to the future of another site, this linkage is usually criterion related, and not a function of a 1:1 correspondence between alternatives. Exceptions to this rule may exist however, such as a vocational/technical site related to a high school -- but these are special cases easily modeled.

Regarding alternatives and their mutual-exclusivity, the major problem lies in curriculum evaluation, where various instructional activities may possess the idential criterion measures across all criteria (or at least, have been measured that way). Such 'toss-up' alternative solutions can be controlled via what we will come to understand as the "objective function" vector within the multiple alternatives model. The multiple alternatives analysis framework will accomodate such identical criterion vectors; but the membership (if it exists) within the solution set can be only considered by chance. The true problem of course is whether or not the two (or more) alternatives in question in essence perform the identical same function, i.e. duplication. The model is not concerned with such potential of duplicity (although it can be programmed to do so), and could unwittingly select both alternatives as members of the solution set. Such a problem is ever existent within the assessment of curriculum activities and objectives; and must be guarded against for the sake of time efficiency and the duplication of expenditures.

Regarding criterion measures, the best example of a conscious effort to reduce any form of duplication (or multi-collinearity) exists in the process used to determine the final criterion set for determining school closures (Wholeben, 1980a).

Using sources which ranged from business and industry, through past attempts at developing main effects models for site evaluation, to the opinions and desires of key community and school personnel -- a set of 62 criterion measures were decreased to a final collection of 24 measures utilizing such statistical techniques as factor analysis and analysis of variance. Criteria were excluded from use within the final closure model if they duplicated an already included measure from another 'supposedly unrelated' criterion, or if they tended to be segregated to a particular kind of site, which was a priori determined *not* to be utilized as a criterion reference. By insuring mutual exclusivity within criterion references, not only was potential duplication of criteria avoided but also was the use of unwanted biasing sources precluded.

For a more technical and manual-oriented presentation concerning the control of mutual-exclusivity in alternatives, the reader is directed not to skip reading the final section of chapter five, concerning the use of tautological inference vectors. Regarding the use of statistical procedures to help determine the degree of mutual-exclusiveness in criterion measures, the reader is directed to study carefully the contents of chapter nine.

# COLLECTIVENESS-EXHAUSTIVENESS IN MODEL PLANNING

Controlled system totality and criterion representativeness are the goals of collective-exhaustivity regarding the preliminary planning for model design and construction. To measure total system impact, all decisional units must be model regardless of their potential for inclusion within the final solution set. Similarly, the effect of a particular criterion reference can not be detected unless it was modeled within the original decisioning process.

## The Issue

While the concept of mutual-exclusiveness focused mainly upon independence and overlap between both the alternatives under investigation, and among the various criterion references utilized in the evaluation of those alternatives -- the idea of collective-exhaustiveness is concerned primarily with the totality of the system being analyzed, and the universality of those impacts attributable to that system.

The collective-exhaustivity based upon the alternatives to be modeled, illustrates the need of a modeling system to address two paramount concerns. First, the alternatives must in fact describe every conceivable potential policy or action which has some degree of expectancy associated with the context being analyzed. It should be noted, that satisfaction of this need for including every possible alternative, may lead to the violation of the mutual-exclusiveness or relatedness between two or more individual alternatives. This should not be considered a detriment to the model. A reliable rule-of-thumb is to exclude only those alternatives which do not demonstrate a different criterion measure on at least one criterion variable. Secondly, this need to describe all possible solutions incorporates the notion that system impact can not be accurately measured without including all potential measures within the systemic modeling procedure. For example, a particular decisioning alternative may not be a candidate for the solution set (due to political, social, economic or religious reasons) -- yet it is reasonable that its 'preclusion' should be modeled in order to attribute its exclusion from the measure of total system impact. Likewise, a particular decisioning alternative may be defined as necessary for inclusion regardless of the measures of its criteria -- and therefore, it legislated inclusion to the total system impact as measured by criteria, must be controlled.

While collective-exhaustiveness is concerned primarily with controlling for total solution likelihood and total system impact, respectively, in addressing the area of constructing alternatives for evaluation -- the concern for the collective-exhaustiveness in defining criterion references is just as important to the model planning process. With criteria, all possible references must be decided and included within the model, to totally assess each alternative's individual contribution to the system impact via its inclusion or exclusion within the solution set; and to assess the collective contribution resulting from the modeling of a multiple-alternatives and/or multiple-entry solution context. All possible criteria which are viewed to have a potential impact upon the final solution set generated must be included within the modeling framework. Selective exclusion will have the same effect as included multiple measures of the same criterion measure for weighting purposes (as discussed above).

## The Application

One of the major errors in evaluating schools for closure during the past few years, has been the conscious exclusion of sites which will not be closed "no matter what". Such a decision is almost always political, and sometimes even valid. The problem stems from the exclusion of the site from comparison with other buildings susceptible to selection -- and thus the unconscious exclusion of the privileged site's criterion measures from being utilized in the final system-wide impact composite. In this situation, the final measure of system impact in not representative of the total system; and is therefore erroneous. Models can be designed to include a privileged site's measures within the final decisioning process; and yet tautologically exclude that same site from the final solution set (schools for closure).

Collective-exhaustiveness with respect to criterion references however, is a much more difficult issue to monitor and control. The experienced evaluator can well remember the multitude of times the question has been asked, "Have all the necessary criterion references to make an informed decision been included?"; and the equal number of times, crossed fingers behind back, the reply was, "All (I hope)." Only time, communication and openness can provide the necessary setting for discovering 'all relevant' references.

The necessity for full criterion representation is best illustrated in the area of fiscal modeling for determining program budgetary roll-backs. Defining the total system impact as those composites which signify effects upon the various object expenditure categories (salaries, benefits, equipments, capital outlay, etc.), the final solution of the budgetary cutbacks can be modeled and/or monitored via examination of the final object sums. For example, if the reduction of equipment expenditures is considered to be of primary importance, program with high need for equipment purchases will be of weighted preference for inclusion within the final solution set. In the same vein, if a goal exists to decrease salaries by some x-percent, the final configuration of the solution set will allow a direct reference to that particular goal.

Thus, the concept of collective-exhaustiveness represents a defined need to not only model the full system as it exists, but also to assure all criterion measures desired within the final decisional process are present. Without such careful preparation, measures of individual as well as collective system impact is impossible.

## INDIVIDUALIZED V. COLLECTIVE SYSTEM IMPACT

Individualized system impact refers to those criterion references which represent a particular alternative's worth to the solution set, and to the system. Collective impact is a composite of all solution set members, and nonmembers -- signifying the benefit of the arrived-at solution to the system as a whole, and the remaining system functioning level.

### The Issue

As might be hypothesized, main-effects modeling within the singular-alternatives' context provides the simplext of all policy (or action) modeling situations. The concept of evaluating policy alternatives for variable utility is often conducted in a setting of multiple alternatives (or multiple-entry solutions), and the resulting reliance upon interactive-effects modeling strategies. Each alternative's individualized contribution to the system, as defined by the measure(s) associated with each criterion reference, can easily be recognized. Usually, each alternative will possess simultaneous measures of both positive benefit and negative impact to the system as a whole, dependent upon which of the particular references are being evaluated. By establishing certain limits on the 'acceptability' of levels of such measurement, alternatives can often be excluded from further consideration as a potential solution -- that is, having failed a particular criterion test. Policy decision-making in reality however, is hardly that absolute.

Realism, and the belief in the fact that there are really no 'perfect' solutions, will lead the decision-maker to understand the need to accept the bad along with the good. If one looks long and hard enough, each and every potential alternative will have some criterion associated with it's impact to the system, that will be 'less than acceptable' to the modeler and the system. Therefore, any modeling context must look to the 'big picture', and understand the total impact to the system as a whole -- that is, the measure of collective system impact.

No where is this more important, than within the multiple-alternatives context. Understanding that no one solution will work, a collection of potential solutions is analyzed until the resulting 'set' defines an acceptable solution to the problem at hand. That is, a group of alternatives will collectively provide the combined impact necessary in order to effect the solution required or desired. The modeling scheme utilized to guide the development of a final solution set must therefore provide for the control of such collective impact; and must moreover allow the necessary compilation of alternatives in seeking a collective effect.

## The Application

Analogous to the creation of a subscale on a psychological battery via the incorporation of the responses to several items, the use of a multiple alternatives analysis framework as a survey questionnaire generator has been studied. From a pool of several hundred potential items, various items (or questions) can be selected as part of a survey questionnaire based upon certain pre-ordained needs or demands of the individual requiring the survey instrument. In this circumstance, viewing each item's contribution to a final "subscale" composite, and the total composite contribution to the system as a whole -- is directed comparable to any of the models previously discussed within this chapter.

Within the itemization version of the multiple alternatives modeling framework, criterion references are related to the degree to which an item has been found to represent a particular view or response to a specific subject; and represents the item's contribution to a 'survey subscale'. Accordingly, the contribution of each of these 'subscales' to the final instrument created by the grouping of these items represents the total instrument's contribution to the construct (or constructs) desired to be surveyed.

All multiple alternatives models -- whether policy or action alternative oriented -- possess the capability of controlling and/or monitoring both individualized and collective system impact, based upon the solution set constructed. In the school closure model, this is related to assuring that the schools remaining open contain enough seating capacity to accomodate current enrollment levels. In the budgetary roll-back model, program budgets are deallocated in order to meet the requirements of a specific, dollar reduction in revenue. In the selection of a micro-computerized system for both instructional and administrative objectives, it is the stipulation that one and only one system can be purchased -- and that this system must be the best in terms of maximally satisfying the prestated objectives.

It remains these ideas of 'best' and 'maximal' which a decision model must somehow operationalize in its systematic pursuit of a successful remediation strategy.

## OPTIMIZATION OF SYSTEM IMPACT

To make the best decision possible without creating new problems, or more realistically without creating new problems more difficult than the initial ones being solved, is the goal of the decisional scientist. Oftentimes, the best decision does not seem to bring relief to the system, only to redistribute the negative impacts somewhat. The model can not solve the problem; it can only in essence display the relative merits of a solution it derives from evaluating the alternative options input to the model, based upon the criterion measures describing those options.

### The Issue

Accepting the negative aspects of a solution along with its postive effects, is a key concept within the decisioning modeling of policy alternatives; and is referred to as systemic optimality. Basically, the model is designed to adopt a specific solution set membership, based upon the criterion measures defining the range of alternatives included within the model, in such a manner that, positive impact to the system as a whole is *maximized*, and negative by-products based upon that same solution *minimized*. The extent to which the system will be allowed to assume negative impact is based upon the model's imposed limits for collective negative effect to the system as a whole (discussed within the previous section). Once again, the modeler must rely upon the conceptual framework of the decision matrix.

With a matrix specifying individual alternative's performance across all criterion references, any combination of alternative solutions may be collectively viewed as to their collective impact to the system as a whole. The initial modeling context is able to further specify the level of positive impact which must be attained or surpassed (i.e. maximization); and denote the level of negative effect which will be tolerated as a limit (i.e. minimization). Such dual demands of maximizing positive impact and minimizing negative effect is known as defining the feasibility region within which the potential decision(s) reside; and therefore constrain the model's search for a 'best of all' solution to the defined problem.

The best solution (multiple-entry or otherwise) will be one which initially does not violate any of the constraints placed upon the feasibility region; and which subsequently provides the highest positive (or lowest negative) impact to the system, as measured by some one or more optimizing criterion references. This is called cyclic optimization, or the cycling of various demands through the model, and the related observation of how such differing demands influence the variable development of different policy alternatives. The final, or optimal solution thus portrays a remediation strategy which not only assures strict adherence to introduced criterion measures and their limits, but also provides the best mix of alternatives which collectively meet the overall demands of the system modeled.

## The Application

A solution is optimal insofar as its represents the best-mix of criterion measures utilized in describing that same solution. The multiple alternatives setting is the clearest example of the constructs underlying solution optimality and integrity.

The 24 criterion measures which were utilized to determine the solution set for site closures, controlled not only individualized impact to the solution but also collective effect to the system as a whole. Of these measures, 18 were designed to demonstrate a positive, desireable impact to the system -- and thus were maximized (e.g. area of the school, current enrollment, history of survival percentages, proximity of enrollees to the site, number of minorities, available classrooms, and physical characteristics in ratio to utility consumption and expenditures). The remaining 16 measures were construed to be negative in scope, and were therefore minimized (e.g. student residence overlap between attendance areas, site overlap between neighboring schools, site age).

Using these criterion measures as defined above, the school closure model was designed so as to demonstrate a solution set which would impact the system (district) as described; that is, close schools with smaller areas, history of survival non-retention, and so forth -- and thereby keep schools with larger capacity for enrollments shifts, closer student residence proximity, and so forth. With this model, 24 individual solution sets were designed in such a fashion, that given the model as controlled by the 24 references input, each criterion reference in turn was given status as guiding the development of the solution -- that is, given the weight of maximizing or minimizing various positive or negative impacts, respectively. In this way, each separate criterion was afforded 'fair advantage' in guiding the model to selecting the best-mix solution of schools to close (both number and name); and each solution set was compared for consistency across all iterations of the modeling execution.

To optimize all criterion measures in such a way as to construct the best, possible solution set, is the ultimate goal of the multiple alternatives model. However, it again must be recognized, that the best solution may not represent all of the individual criterion impacts desired by the initial modeling design.

## PREFERENCE AND TRADE-OFF CONTINGENCIES

Since decision-making is often a form of collective bargaining and personal arbitration, it is relevant for a decisioning model to contain features of such selective compromise. All decisioning contains criterion-related ingredients of preference -- that is, for the final solution set to manifest particular, desireable qualities. Equally relevant then, is the need to incorporate the ability to 'trade-off' certain virtues in order to arrive at a solution for benefiting the system as a whole.

### The Issue

In planning and designing a modeling strategy for evaluating policy alternatives, the model building must be willing to accept 'less than normally acceptable' solution alternatives based upon measures associated to one or more criterion references. Furthermore, any reasonable model must incorporate a mechanism by which the decisioning process (viz., the building of the solution set) is able to analyze and determine preferences based upon the interaction of the criteria with the combination of potential alternative actions.

Preferences can be modeled into such a framework via the use of weighted criteria; that is, allowing greater influence for a select number of criterion references as opposed to the remaining measures utilized. In the same way, trade-offs are modeled through use of collective measures to signify system impact as a whole (i.e. mazimizing the positive, and minimizing the negative). Since it is likely that 'perfect' solutions will be impossible, the model must be able to understand the limits within which it will operate, and the subsequent listing of both positive as well as negative impact to the system, based upon the solution formulated.

## The Application

This final issue in chapter three provides constant fuel for the critics of quantitative, decision modeling. The fact that many final, solution sets will not exhibit all of the modeled criterion constraints upon the solution, leads the novice to believe that the framework has failed, and that its use is therefore unwarranted.

All decisioning has preferences as illustrated by the direction given to the various criterion measures -- to maximize the positive impact to the system, and to minimize the negative. The development of a solution set, will ofter incorporate some undesireable measures in order to allow the positive impact which would result. This is the acknowledged existence of trade-offs as represented within the results of the multiple alternatives model; and it is maintained as a strength of the model to be able to make such trade-offs as it progresses toward building a solution set.

In a post-hoc evaluation of the school closure model for example, it was found that all criterion measures which were to be maximized, were -- and likewise for those to be minimized. That is, the solution set displayed a consistent array of 'negatively' oriented measures as opposed to those schools which remained open. However, some closed sites resembled many of the opened sites on one or two criteria. These sites were decisioned as closed based upon the predominance of their impact as measured by the criteria, and therefore upon their impact to the system as a whole.

# CHAPTER 04

# THE DESIGN STAGE

### [ Multiple Alternatives Analysis as a Mathematial Decisioning Model ]

# THE TECHNIQUE

To include or not to include a more detailed and technical decision of the mathematical design within the MAM -- was a long and arduous decision for the author. On the one hand, inclusion of a technical section (I reasoned) might sensitize the general reader negatively; and preclude that reader's pursuit of the remaining text. On the other hand, exclusion of that same section (I rationalized) might very well undermind the final acceptance of this report as a valid technique.

The final decision to include at least some minimal amount of technical development was made, based upon four premises:

(1) though a technical decision may in fact threaten some readers, the Multiple Alternatives Model is (also in fact) a technical design, for which I neither minimize nor apologize;

(2) a technical discussion will add credence to the operating mechanisms of the model, illustrate its interworking parts, and promote a detailed understanding of the "input-process output" relationship -- far above any "Trust me, it really works!" manuever;

(3) the technical formulation can be both informative and documentary, without reading like a biochemist's report on the postpituitary hormone, oxytocin (that is, $C_{43}H_{66}N_{12}O_{12}S_2$, if you are interested); and

(4) a responsible reading of Chapters two and three has already acquainted the reader to the general ideas contained within Chapter 4; that in fact, Chapter four

should be a 'recall' episode for the material already alluded to in the previous fiscal discussion.

The presentation in Chapter four consists of three sections which follow a very simple introduction, design, and evaluation/validation paradigm. The discussion is void of any particular problematic context; and thus is more generic than system-specific in scope. Such an inductive approach, viz. from the specific in Chapters two and three, to the universal in Chapter four, will hopefully not only promote better learning and understanding of the MAM technique, but will moreover induce the reader to review the manuscript more closely for its intuitive and generalizable applications to other problem areas of education.

# INTRODUCTION TO THE MULTIPLE ALTERNATIVES MODEL

The Multiple Alternatives Modeling (MAM) framework makes four assumptions of the problem (decisioning) areas to which it (model) is to be applied. First, the problem is a multiple alternatives problem, requiring a multiple alternatives solution. That is, the solution to the specified problem situation could reasonaly call for the implementation of more than one of the alternative courses of action being evaluated. Whether it be schools to be closed, budgets to be cut, programs to be initiate, or routes over which to transport students --greater than one school, budget, program or route may be selected as the solution.

Secondly, criterion reference points (i.e., variables) can be quantitatively measured for each of the defined alternatives, demonstrating an alterative's impact (if implemented) to the system, according to the criterion's derived focus. Furthermore, this arithmetic summation of all 'selected' alternative's criterion values (across a particular criterion) forms a composite numerical value which illustrates the solution's impact (selected alternatives) to the system as a whole.

Thirdly, the system being modeled can afix some high (or low) limits to these criterion summations, called upper (or lower) bounds. If a criterion measures the total cost of each program being considered for implementation, and a total available budget of some specified amount exists -- then the summed total of all program budgets (for the program to be implemented) must be equal to or less than the total available budget. Obviously, you cannot spend more than you have available (although program administrators do it religiously). In this example, the total budget available is seen as an 'upper bound'. Similarly, a 'lower bound' could be the total amount to be cut from an operating budget, where the criterion is the cost-to-be-saved for each of the potential alternative programs (budgets) available for roll-back.

*Finally*, some one, individual criterion measure is identified which will be utilized to optimize the selection of the final alternative mix-set (solution. Many sets of alternatives (that is, combinational permutations) can usually be identified which will provide a solution to some degree or extent. However, reality normally requires an adherence to some priorities existent within the system being modeled; for example, a desire to *maximize* the number of students transported (on the average) via each bus; or a desire to *minimize* the number of stops a bus has to make enroute to the school.

The Multiple Alternatives Model is a complex response to a complex decisioning situation. The model recognizes the need to simultaneously evaluate all available alternatives across all defined criteria, and to therefore simulate the interactive nature of a criterion-inferenced, decision-making environment. Above all else, the MAM framework provides a ready means for evaluating a set of alternatives, collectively -- and based upon the set of criteria which the real-life decision-makers have posited as the desired ingredients of their final decision.

## Role of Multiple Alternatives in Decision-Making

In the multiple alternatives context, the potential solution alternatives may be displayed as a serial string; that is, $x_1 \; x_2 \; x_3 \; \ldots \; x_n$ where $x_j$ represents the jth alteratives (of n total), $j = 1, 2, \ldots, n$. The MAM decision is to include (or exclude) each alternative as a member of the final solution (mix-set). The only value which $x_j$ may assume is '1' (that is, to *include*) a '0' (that is, to *exclude*). Therefore, the decision is to mathematically assign either the value of 1 or 0 to each of the $x_j$ alternatives, $j = 1, 2, \ldots, n$; thus the label, *binary, integer* programming.

In each case of ten alternatives, the serial representation would be illustrated as:

$$[\, x_1 \quad x_2 \quad x_3 \quad \ldots \quad x_{10} \,]$$

If the final solution included alternatives 2, 5, 9 and 10 as members, then the *solution vector* would be displayed as

$$[0 \;\; 1 \;\; 0 \;\; 0 \;\; 1 \;\; 0 \;\; 0 \;\; 0 \;\; 1 \;\; 1].$$

As we will see in the next section, the function of a binary coding (0,1) extends beyond its use as an easy display mechanism for alternative solution membership.

## Decision Criteria as Modeling Constraints

We have seen that an alternative becomes part of the solution by taking on the value of 1 (that is, $x_j = 1$ for some j of n); as opposed to the value of 0 ($x_j = 0$, for all j of n, such that $x_j = 1$, $j = 1, 2, \ldots, n$). The basis for assigning 1's v. 0's, lies in the evaluation of the criteria which were selected and measured to indicate each $x_j$'s impact upon the system being modeled. Furthermore, it was the summation of the criterion values across the *selected* (solution) alternatives which formulated the multiple alternatives solution (mix-set) impact to the system.

Let us define an 'a' as representing the value of any criterion for any alternative. It is relatively straightforward then to interface $a_{i_j}$ as the value of the ith criterion's measure for the jth alternative. For example, recall our previous example of ten alternatives. If there existed only one criterion to assist us in evaluating the set of potential solutions, then the criterion values could be represented as:

$$[\; a_{1,1} \quad a_{1,2} \quad a_{1,3} \quad a_{1,4} \quad \cdots \quad a_{1,10} \;]$$

In a more complicated example, a set of three criteria used to evaluate ten alternatives would be represented as:

$$\begin{array}{l} [\; a_{1,1} \quad a_{1,2} \quad a_{1,3} \quad a_{1,4} \quad \cdots \quad a_{1,10} \;] \\ [\; a_{2,1} \quad a_{2,2} \quad a_{2,3} \quad a_{2,4} \quad \cdots \quad a_{2,10} \;] \\ [\; a_{3,1} \quad a_{3,2} \quad a_{3,3} \quad a_{3,4} \quad \cdots \quad a_{3,10} \;] \end{array}$$

The first case involving only a single criterion, is called a vector of criterion values across the potential alternatives. The second case where three criteria existed, is called a matrix (i.e., a collection of two or more vectors) of criterion values across potential alternatives. Since most MAM problems involve more than a single criterion, and because each criterions' measure will be utilized to constrain the decision to be made (or more appropriately guide the selection of alternatives for inclusion within the solution set), the matrix is known as the constraint matrix.

At this point, we have introduced the variables of $x_j(j = 1,2,\ldots, n)$ and $a_{i_j}(i = 1,2, \ldots,m;j = 1,2,\ldots,n)$ to represent the alternatives and criterion values, respectively; that is:

|  | $x_1$ | $x_2$ | $x_3$ | $\cdots$ | $x_n$ |
|---|---|---|---|---|---|
| 1st criterion: | $a_{1,1}$ | $a_{1,2}$ | $a_{1,3}$ | $\cdots$ | $a_{1,n}$ |
| 2nd criterion: | $a_{2,1}$ | $a_{2,2}$ | $a_{2,3}$ | $\cdots$ | $a_{2,n}$ |
| . | . |  |  |  | . |
| . | . |  |  |  | . |
| . | . |  |  |  | . |
| mth criterion | $a_{m,1}$ | $a_{m,2}$ | $a_{m,3}$ | $\cdots$ | $a_{m,n}$ |

Can you see (?) that a further refinement of the above scheme could be made to appear as follows:

$$\begin{array}{lllll} [\; a_{1,1}\,x_1 & a_{1,2}\,x_2 & a_{1,3}\,x_3 & \cdots & a_{1,n}\,x_n \;] \\ [\; a_{2,1}\,x_1 & a_{2,2}\,x_2 & a_{2,3}\,x_3 & \cdots & a_{2,n}\,x_n \;] \\ \quad\vdots & & & & \vdots \\ [\; a_{m,1}\,x_1 & a_{m,2}\,x_2 & a_{m,3}\,x_3 & \cdots & a_{m,n}\,x_n \;] \end{array}$$

This makes sense if you recall that: (1) the value of each $x_j$ will be either a '0' or a '1', depending upon whether it is excluded or included within the solution set; and that (2) the sum of the criterion values measures the total impact of the solution upon the system.

Consider a relatively small example of four alternatives being measured across three criteria. Thus the model would be represented as:

$$a_{1,1}x_1 + a_{1,2}x_2 + a_{1,3}x_3 + a_{1,4}x_4 \quad \text{(system impact if CRIT \#1)}$$

$$a_{2,1}x_1 + a_{2,2}x_2 + a_{2,3}x_3 + a_{2,4}x_4 \quad \text{(system impact if CRIT \#2)}$$

$$a_{3,1}x_1 + a_{3,2}x_2 + a_{3,3}x_3 + a_{3,4}x_4 \quad \text{(system impact if CRIT \#3)}$$

Now if the solution vector $[x_1 \quad x_2 \quad x_3 \quad x_4]$ was represented as $[1 \quad 0 \quad 0 \quad 1]$ where only alternatives #1 and #4 were selected, the model would be shown as:

$$a_{1,1}(1) + a_{1,2}(0) + a_{1,3}(0) + a_{1,4}(1)$$

$$a_{2,1}(1) + a_{2,2}(0) + a_{2,3}(0) + a_{2,4}(1)$$

$$a_{3,1}(1) + a_{3,2}(0) + a_{3,3}(0) + a_{3,4}(1);$$

or in reduced form:

$$a_{1,1} + a_{1,4} \quad \text{(solution impact if criterion \#1)}$$

$$a_{2,1} + a_{2,4} \quad \text{(solution impact if criterion \#2)}$$

$$a_{3,1} + a_{3,4} \quad \text{(solution impact if criterion \#3)}$$

We now see why previous discussions of tradeoff/preference and interactive-effects were germane to the MAM development. Note that if $[1 \quad 0 \quad 0 \quad 1]$ is to be our solution, then the values of $[a_{1,1}, a_{2,1}, a_{3,1}]$ exist for $x_1$ and $[a_{1,4}, a_{2,4}, a_{3,4}]$ for $x_4 = 1$. Thus the solution $x_j$, $j = 1,4$ requires that we accept the criterion values of $(a_{1,j}, a_{2,j}, a_{3,j})$, $j = 1,4$ whether they are most desireable or not. What we also know is that the choice of $x_1$ and $x_4$ as solutions must coincide with the upper/lower value restriction placed upon the criteria.

## System Demand and System Impact

The limits placed upon each of the composite measures formed by summing each criterion's impact across all solution alternatives (i.e., $x_j = 1$ for some j of n), reflect two closely related, system-stimulated components: demand and impact. System demand exemplifies the need(s) of the system by the demand(s) placed upon the value composites of each criterion summation; that is, the upper or lower bounds of the criterion sum across the selected solution alternatives. However, since the bound is established only as a limit (not to be violated), then it is reasonable to assume these sums will seldom be equivalent to the bounded value; that is, the composite may be somewhat less than the established upper bound, or somewhat greater than the established lower bound. The actual value and its distance from the bounded value, is the measure of system impact (for each criterion of the alternatives selected as solutions).

Based upon the already linear relationship between the criterion values and alteratives (defined as coefficients and independent variables, respectively), it is a simple extension to model these criterion limits as a function of inequalities. Thus in a threealternatives, two-criterion model (requiring a 2 x 3 constraint matrix, right?) -- where the first criterion has an upper-bound required, and the second criterion a lower-bound -- the representation may be stated as:

$$a_{1,1}x_1 + a_{1,2}x_2 + a_{1,3}x_3 \leq b_1$$

$$a_{2,1}x_1 + a_{2,1}x_2 + a_{2,3}x_3 \geq b_2$$

where $b_i (i = 1,2)$ are the upper and lower limits of the first and second criteria, respectively. These values $b_i$ are known as the values of the right-hand side (RHS) of the constraint matrix; the values $b_i$ in vector format $(b_1,b_2)$ are referred to as the entries of the conditional vector. Therefore if the solution vector [1 1 0] is to be analyzed, the following algebraic relationship must be satisfied:

$$a_{1,1}x_1 + a_{1,2}x_2 \leq b_1$$

$$a_{2,1}x_1 + a_{2,2}x_2 \geq b_2$$

If moreover a particular constraint (criterion relationship) exists such that an equality is required, the linear equality:

$$a_{i,1}x_1 + a_{i,2}x_2 + \ldots + a_{i,n}x_n = b_i$$

is useful and valid.

The utility of linear equalities and inequalities in formulating the multiple alteratives model is obvious. However, it is reasonable to expect a situation in which more than one set of alternatives provides a solution to the MAM problem. In these cases, additional system priorities must be set.

## System Priorities and the Objective Function

Consider the circumstance where in evaluating the above three-alternative, two-criterion problem, two plausible solution sets became evident: [1 0 1] and [0 1 1]. Since both are plausible, we now that each of the relationships:

$$a_{1,1}x_1 + a_{1,3}x_3 \leq b_1$$

$$a_{2,1}x_1 + a_{2,3}x_3 \geq b_2$$

and

$$a_{1,2}x_2 + a_{1,3}x_3 \le b_1$$

$$a_{2,3}x_3 + a_{2,3}x_3 \ge b_2$$

are individually, simultaneously satisfied. The question becomes: how to choose between the first ([1 0 1]) and second ([0 1 1]) sets?

The MAM framework provides a solution to this dilemma, via the use of another crierion called the objective function (or cost vector). Unlike the criterion constraint inequalities, the objective function does not have an established upper (or lower) bound assigned. Rather the criterion coefficients for the objective function (labeled $c_j$, $j = 1,2,\ldots,n$) are summed and the additional deman established that either a maximum or minimum sum be found. Consider the following scheme:

(Alternatives)

| | $x_1$ | $x_2$ | $x_3$ | | RHS |
|---|---|---|---|---|---|
| criterion #1 | $a_{1,1}$ | $a_{1,2}$ | $a_{1,3}$ | $\le$ | $b_1$ |
| criterion #2 | $a_{2,1}$ | $a_{2,2}$ | $a_{2,3}$ | $\ge$ | $b_2$ |
| (objective function) | $c_1$ | $c_2$ | $c_3$ | | |

If the criterion referencing the objective function was of a positive-consequent nature, that is measuring good effects of each of the potential alteratnives, then it is reasonable to desire a maximum value from the summation of $c_j$ based upon the alternatives selected as solution.

If the solution [1 0 1] is selected, then the evaluation of:

$$c_1x_1 + c_2x_2 + c_3x_3$$

results in the composite:

$$c_1 + c_3 .$$

Likewise, the solution set [0 1 1] results in the composite:

$$c_2 + c_3 .$$

If $c_j$ are positive (i.e., good and desireable) measures and we therefore wish to maximize the $c_j$ summation -- it is intuitive that the greater of the $((c_1 + c_3)$ and $(c_2 + c_3))$ values will decide the final choice between the [1 0 1] and [0 1 1] sets, respectively. That is, if in fact $(c_2 + c_2) > (c_1 + c_3)$, then the relationship:

$$\text{maximize } c_1x_1 + c_2x_2 + c_3x_3$$

yields the solution set [0 1 1] with a maximized objective function of $(c_2 + c_3)$. The idea of maximizing (the "good") and minimizing (the "bad") the summation of the objective function coefficients, demonstrates the issue of optimal v. feasible solutions. Both [1 0 1] and [0 1 1] were feasible solutions in that both satisfied the limits established via the inequalities and the values of the RHS or conditional vector. However, the [0 1 1] solution was optimal as it alone maximized the objective function summation.

In summary, this example could have been stated completely in the MAM framework as follows:

$$\text{To } \underline{\text{maximize}}: \quad c_1x_1 + c_2x_2 + c_3x_3$$

$$\underline{\text{subject to}}: \quad a_{1,1}x_1 + a_{1,2}x_2 + a_{1,3}x_3 \leq b_1$$

$$a_{2,1}x_1 + a_{2,2}x_2 + a_{2,3}x_3 \geq b_2$$

$$x_j = (0,1),\ j = 1,2,3.$$

The next section will focus in greater detail on the actual quantification of the coefficients; and the development of bounds for the conditional vector.

Figure 7. Representation of the Augmented Decision Matrix Model as the "Multiple Alternatives Model" (MAM).

(Decision Variables)

|  | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | $x_6$ | $x_7$ | $x_8$ |  | (RHS) |
|---|---|---|---|---|---|---|---|---|---|---|
| Constraint #01 | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ | $a_{15}$ | $a_{16}$ | $a_{17}$ | $a_{18}$ |  | $b_1$ |
| Constraint #02 | $a_{21}$ | $a_{22}$ | $a_{23}$ | $a_{24}$ | $a_{25}$ | $a_{26}$ | $a_{27}$ | $a_{28}$ | . . . | $b_2$ |
| Constraint #03 | $a_{31}$ | $a_{32}$ | $a_{33}$ | $a_{34}$ | $a_{35}$ | $a_{36}$ | $a_{37}$ | $a_{38}$ | $\leq$<br>=<br>$\geq$ | $b_3$ |
| Constraint #04 | $a_{41}$ | $a_{42}$ | $a_{43}$ | $a_{44}$ | $a_{45}$ | $a_{46}$ | $a_{47}$ | $a_{48}$ | . . . | $b_4$ |
| Constraint #05 | $a_{51}$ | $a_{52}$ | $a_{53}$ | $a_{54}$ | $a_{55}$ | $a_{56}$ | $a_{57}$ | $a_{58}$ |  | $b_5$ |

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| $c_1$ | $c_2$ | $c_3$ | $c_4$ | $c_5$ | $c_6$ | $c_7$ | $c_8$ |

(Cost Vector Coefficients)

OPTIMIZE: $\sum_{j=1}^{8} c_j x_j$ st: $\sum_{j=1}^{8} a_{ij} x_j \ (\leq, =, \geq) \ b_j \quad x \geq 0$

(If MILP, x is integer; if decisonal, x=0,1 only.)

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## DESIGN OF THE MULTIPLE ALTERNATIVE MODEL

Simply stated, the Multiple Alternatives Model is a collection of simultaneous linear equations and inequalities, with an additional string of serial values (the *objective function*) available to "break any ties" which result when mover than one vector of solution values (0,1) exists for the *independent variables* (the multiple alternatives). Generally speaking, these equations and inequalities which make up the *constraint matrix* and *conditional vector* (righthand-side) could be further labelled as the *dependent variables* (the foci of the particular *criterion constraints*).

The coefficients of the criterion constraints, the $a_{ij}$ values, reflect measures for each of the $x_j$ alternatives ($j = 1,...,n$) across each of the defined i-criteria ($i = 1,...,n$). The $b_i$ values ($i = 1,...,n$) of the RHS (right-hand-side) represent the limits (upper and lower bounds) placed upon the sums of each criterion, summated across all selected (i.e. solution) alternatives. Since a selection means that the specific $x_j$ value will equal '1', then the criterion value $a_{ij}x_j$ (or $a_{ij}$ times 1) forces $a_{ij}$ to be an added to the sum.

We may now improve tremendously upon our earlier characterization of the decision matrix. By adding the ideas of the conditional vector (to insure flexibility and the potential for tradeoff/preference), we are able to model the *interactive-effects* premise required of multiple-alternatives decisioning. Supplementing the model further with an objective function, the set of feasible solution alternatives can be further analyzed to choose the singularly best alterative mix-set -- the *optimal* solution. Figure 7 displays the scheme of the augmented model, within the original eight-alternative/fiveconstraint milieu. We may now proceed to discuss in greater detail the measurement and operational schemes which are possible (and desireable) within the MAM framework.

## Generation of Collectively-Exhaustive Alternatives

Valid construction and reliable execution of the MAM system requires the user to recall certain rudimentary facets of basic research and experimental design, and statistical analysis -- the issues of collective-exhaustiveness and mutual-exclusiveness. We will delay the discussion of the mutual exclusivity of selected alternative solutions until a later section. However, the issue of collectively-exhaustive alternatives is germane now.

Recall the two 'strong suits' (obviously among many) of the MAM framework: (1) control of interactive effects modeling, and (2) measure of total system impact. Interactive-effects modeling provided a control over the rather complex milieu produced, when decision-making was evaluating multiple alternative solutions across multiple competing criteria. Single alternatives could be measured as "good" or "not-so-good" on various criteria - compared to the correlated criterion measures of other alternatives, and analyzed as to which alterative displayed the best-mix of criterion measures. When compared, however, did some set of alternative solutions produce a better "interactive-mix" than another set? And, were different amounts of alternatives required for either? Thus, interactive-effects modeling assumes highly complex interrelationships not only between sets of multiple alterantives and among (within) those same sets; but also presumes related interactions between the criterion measures of those same alternatives (both singular and multiple) --the necessary foundation for a trade-off/preference potential.

The other 'strong suit' of MAM centers about the issue of measuring total system impact. You will recall, that the RHS-values provide a control upon the summation of each criterion constraint --thus limiting the impact which the selected alternatives will be "allowed" to foster. However, RHS-values establish either an upper-or lower-bound to the summation, not the actual value which the summation must assume. Therefore, the true sum for any criterion constraint might very will (and usually will be) different than the pronounced limit; that is, somewhat less than the upper-bound, or somewhat greater than the lower bound. In this way, the desired impact to the system is controlable but moreover the actual impact to the system is measureable. By knowing the discrepancy between the desired and actual impact, the MAM model can be used to detect changes to the system (i.e., differential impact) which may occur through the selection of different alternative solutions.

It should be obvious to the reader that neither the control of interactive-effects nor the recognition of system impact via varying alterantives' configurations, is possible without the existence of all possible, feasible, and relevent alternative courses of action for consideration. More succinctly, the set of multiple alterantives being evaluated across the defined criteria constraints must exhibit the characteristics of a collectively-exhaustive population of alternatives. The exclusion of any alternative form the model, automatically precludes its impact upon the evaluation of the remaining alternatives, and its impact upon the system as a whole.

## Criterion Measurement and Constraint Formation

Since the criterion constraint represents a linear relation (either equality or inequality) of the form:

$$a_{i,j}\, x_j + a_{i,j+1}, x_{j+1}, + \dots + a_{i,n}\, X_n \ (\leq, =, \geq)\ b_i$$

or more concisely:

$$\sum_{j=1}^{n} a_{i,j}\, x_j \ (\leq, =, \geq)\ b_{i,} \text{ for each } i = 1, \dots m,$$

extreme caution must be used in developing the $a_{ij}$ coefficients of the $x_j$ decision variables. Obviously, each $a_{ij}$ must be numeric; and further exhibit such qualities as to allow their arithmetic sum to be a rational and useable quantity for comparison with the associated $b_i$) RHS-value (discussed in the next section).

Four basic scaling schemes exist for measuring and encoding data: nominal, ordinal, interval and ratio. Progressively inclusive, all can be utilized to formulate the $a_{ij}$ coefficient, dependent upon the definition of the particular criterion constraint (i.e. its focus). The most common scales utilized are the interval and ratio measures, due to their ability to compute measures of central tendency (arithmetic means) and distributive variation (standard deviation). We will limit our discussion to these scaling techniques only.

Data concerning program expenditures (e.g. in dollar-units), number of required personnel (e.g. in FTE-units), or energy consumption (e.g. in BTU-units) are easily ratio-scaled measures. Other data which might be obtained from sample opinionnaires concerning the respondent's perceptions towards each particular alternatives might easily be interval-scaled (e.g. a six-point continuum measure associated with a 'Strongly Disagree, ..., Strongly Agree' response format).

Consider the objective:

> "To deallocate such program alternatives as will secure an expenditure savings at least some amount '$SAVE'."

Clearly if we cost-out each program alternative and arrange the constraint as follows:

$$\$_{i,1}\ x_1 + \$_{i,2}\ x_2 + \$_{i,3}\ x_3 + \ldots\ \$_{i,n}\ x_n \geq \$SAVE,$$

then the solution vector $[x, x_2, x_3 \ldots x_n]$ must be of such (0,1) configuration as to allow the sum of the $\$_{i,j}$ to be at least the amount $SAVE or greater. This is one of the easier examples of the use for a ratio-scaled criterion.

Consider another objective for use of the interval-scale:

> "To deallocate such program alternatives as will coincide with the public's opinion of each program's relative lack of merit."

Suppose that a questionnaire was sent to a random sample of individuals, wherein the question was asked:

> "Program $x_j$ fulfills the needs of the community to which it applies."

and the response tallied via the use of the following format:

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly Disagree | Disagree | Moderately Disagree | Moderately Agree | Agree | Strongly Agree |

where a lesser magnitude (i.e. 1, 2, ... ) displayed the respondent's disagreement with the item elicitor, and this measured a negative response to the perceived merit for each of the programs. If 100 people responded to these items (one for each program alternative), the 100 perceptions (1, 2, ..., 6) could be averaged and compiled into the constraint serial:

$$PCP_{i,} \; x_{i}, + PCP_{i,2} \, x_2 + \dots + PCP_{i,n} \, x_n$$

where $PCP_i$ is the ith constraint, and represents the group's (N=100) perception (PCP) of worth or merit for each program. Of course, a value for the RHS ($b_i$ must be computed; and we will survey this development in the next section.

The importance of each criterion constraint within the constraint matrix lies in its ability to model each alternative singularly (via the individual $a_{i,j}$ values), and collectively (via the summation of the $a_{ij}$, j=1,...,n). Singular modeling allows the individual alternative's contribution to interaction-effects to be input to the decisioning model. Collective modeling then allows the impact to the total system of potential solutions to be comparatively evaluated against the established bounds of the conditional vector.

## Computation of the Conditional (RHS) Vector

The need to limit the constraint coefficient summations for a realistic simulation of the system being modeled, as well as the use of these same summations to detect system impact, should now be (hopefully) obvious to the reader. If one wishes to limit the extent of some negative effect to the system via the alternatives selected, then some upper bound is established for the sum of criterion coefficients which represent this negative impact. Similarly, if the modeler wishes to force some level of positive impact, a lower bound would be defined for the sum of 'positive' criterion coefficients, stating that this minimal sum must at least be attained. What may not be so clear yet, is how these limits are arrived at.

One of the authors has performed considerable research in the different ways to develop the RHS-values in the conditional vector. These efforts have produced two basic methods for generating the RHS (the first, static, meaning to be established a priori, and therefore non-varying; the second, dynamic, meaning to be defined algebraically within the model, the value(s) varying as the model varies in its search for a solution). The most common method is the static approach because of its ease in modeling and the acceptability of its assumptions. We will limit our discussion at this time therefore, to the static RHS-value generation technique.

First let us review what we are attempting to accomplish with the linear inequality. Coefficients have been asisgned to each of the alternatives-solution independent variables (the multiple alternative decisions being analyzed), based upon the focus and intent of the particular criterion being modeled (as a constraint). Ecexution of the models will sum various subsets of the set of coefficients defining that criterion; and will repeatedly compare that sum to the RHS limit assigned in the conditional vectors; that is:

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_j \quad \text{(negative impact)}$$

on,

$$\sum_{J=1}^{n} a_{ij}\, x_j \geq b_i \qquad (\underline{\text{positive}} \text{ impact}).$$

Recall also that the $b_i$ value is to denote impact to the system as a whole; that is, the collective impact of the subset of decision alternatives being evaluated as a potential solution. If we think of "as a whole" and "collective impact" in the arithmetic sense, a useful analogy is the arithmetic average or mean. That is, the system will average the coefficients' value being analyzed; and compare this average value with the sum of the coefficients.

To accomplish this, the modeler first needs to predict how many decision alternatives ($x_j$) are likely to be selected for the final solution; let us say 'k'. Then the modeler computes the mean of the coefficients for a particular criterion,

$$\bar{A}_i = \frac{\sum_{j=1}^{n} a_{ij}}{m}$$

and multiplies the mean value $A_i$ by the expected number (amount) of multiple solutions,

$$b_i = k \cdot \bar{A}_i =$$

where $b_i$ is the RHS-value to be compared with the constraint coefficient (subset) sum. Thus,

$$\sum_{j=1}^{n} a_{ij}x_j \leq k \cdot \bar{A}_i$$

where the number of j's approximate the value of k.

Unfortunately, experience shows the use of the mean (alone) to be substantial in establishing a workable $b_i$ value, this problem is easily rectified by introducing the standard deviation of the criterion coefficients to the $b_i$ formula. Remembering that the standard deviation $SD_A$ is obtained from:

$$SD_A^i = \left[ \frac{\sum_{j=1}^{n} (A_i - a_{ij})^2}{n-1} \right]^{\frac{1}{2}}$$

we can now modify the $b_i$ generation formula as follows:

UPPER BOUND $b_i = k \cdot (A_i + SD_A)$

such that,

$$\sum_{j=1}^{n} a_{ij} x_j \leq k \cdot (A_i + SD_A)$$

LOWER BOUND $b_i = k \cdot (A_i - SD_A)$

such that,

$$\sum_{j=1}^{n} a_{ij} x_j \geq k \cdot (A_i - SD_A).$$

Use of the mean and standard deviation provides a consistent format for constraining the decisioning matrix; and each constraint, therein. Not only is systematic flexibility afforded to the model as it searches for a unique (optimal) subset of solution alternatives, but the problems associated with initial system infeasibility are minimized. The notion of infeasibility will be covered in greater detail in a later section of this paper.

## Cyclical Optimatization Via Iterative Objective Functions

In our earlier discussion of the role of the objective function (or cost vector) in gaining the most optimal solution (decisioning alternatives subset) from the available feasible solution subsets (acceptable to established constraints), the reader may have become aware of the subtle bias the OF-coefficients place upon the final solution. Often, this bias is intended. As often, however, it provides "fuel" for model critics to attack the MAM procedure as another "computerized, mathematically gerrymandering" technique. A satisfactory solution to this 'potential' problem is available, and relatively easy to implement.

The idea of cyclical optimization involves the cycling of each constraint entry (i.e. the coefficients $a_{ij}$ of the constraint matrix) through the objective function. Generally speaking, this involves re-executing the model i-times, once for each of the defined constraints where:

$$c_{ij} = a_{ij},$$

each i-th iteration.

Since we either maximize or minimize the sume of the $c_j$ values, depending upon their positive or negative focus respectively, cyclical optimization must be structured to then maximize the objective function when the constraint values being cycled aare of a 'positive impact' nature. And of course, the reverse being true for the negative-impact constraint focus.

The MAM structure thus involves an optimization strategy, which may be depicted as:

$$\begin{matrix}\text{MAX}\\ \text{MIN}\end{matrix} \sum_{j=1}^{n} c_{ij}x_j \quad \text{for each ith iteration}$$

$$\underline{\text{subject to}}: \quad \sum_{j=1}^{n} a_{ij}x_j \ (\leq, =, \geq) \ b_i$$

$$c_{ij} = a_{ij} \text{ for all } i \text{ of } m;$$

$$x_j = 1,0 \text{ for some } j \text{ of } m.$$

Cyclical optimization does not eliminate the bias of the objective function; but rather allows each constraint focus to similarly bias the result of the solution subset selection. As we will see in a later section on "solution teaching," the cycling of each constraint through the objective function provides a most useful technique for studying total system impact.

## Evaluation of the Multiple Alternatives Model

After rather detailed treatments of the design and construction of the MAM framework, additional discussion concerning the model's evaluation (that is, implementation and execution) may seem redundant to the reader. Obviously, the model is designed in full acknowledgement of the way in which it will 'work' to select alternative solutions. And the authors have gone to considerable length to indicate how the model will react to the various changes in its design and development.

But execution of the Multiple Alternatives Model is not in itself a "static" process. As a system of simultaneous linear inequalities, varying configurations of the solution vector $[x_1 \;\; x_2 \;\; x_3 \;\; \ldots \;\; x_n]$ will produce different interaction effects among the criterion constraint coefficients, effecting directly their sums and thus their ultimate comparison to the established RHS-bounds. It is conceivable (and unfortunately occurs often), that the initial relationship between the constraint matrix and conditional vector produces what is known as an infeasible region. The model must then be revised by relaxing one or more of the constraint summation limits, in order to determine (locate) an initial feasible space, and its associated parameters ($b_i$ values). Since the relationship between criteria across alternatives (viz., interactive effects modeling) is not immediately evident in an infeasible situation, considerable time can often be expended in locating the "problem" RHS-value (or values).

Execution also refers to a previously discussed notion of cyclical optimization; and the differing solution vector subsets which usually result when the objective function is replaced by different values. The modeler must keep track of the different solution vectors (thus the term, solution teaching), and observe the nature of each cyclical-OF impat upon the system's final solution.

If the above few paragraph's still sound like "Cicero's oration to the pretorium," then we have not errored by including this section.

## Total System Impact Via Multiple Competing Constraints

As each potential solution alternative competes with other alternatives for inclusion within a solution set, so also does any particular permutated solution subset compete with other feasible solution vector alternatives. The formation of the optimal solution vector occurs as the system asks itself these questions during execution:

(1) how many alternatives will occupy the solution vector?

(2) which alternatives will be selected?

(3) will these (e.g.) three alternatives better fit the constrained system optimally, versus these other five?

(4) will in fact any combinational permutation of the alternatives being modeled satisfy the constraints?

(5) which constraints "constrain" more than others? which less?

(6) if the conditional vector is comprised of desired impact, how close can the model select an optimal solution vector, and minize the desired v. actual

$$(b_i - \sum_{j=1}^{n} a_{ij}x_j) \text{ values?}$$

(7) what tradeoffs/preferences have been made based upon the criteria as a whole, in the selection of one feasible solution subset over another.

Thus, impact to the system being modeled is bsed upon both the selection of the solution vector subset and the related criterion constraints. It is this complicated interrelationship between alternatives and criteria (*viz*., interactive effects modeling) which makes the MAM an outstanding criterion-referenced, decision-making tool.

## Initial System Feasibility and Constraint Relaxation

The MAM framework cannot systematically evaluate solution subsets for an optimal configuration until *system feasibility* has been initially established. Feasibility simply means, that at least one solution vector configuration exists which will satisfy the modeled criterion constraints (linear inequalities). If no such configuration exists (that is, the solution vector is a zero vector [0 0 0 ... 0], then the system is declared infeasible. Although subtle, the occurrence of a zero-vector is a most important (albeit, frustrating) result.

If the system has been carefully simulated and modeled via valid criterion constraints, with the RHS-values accurately reflecting system needs and/or demands -- then the result of a zero-evctor simply means that *no alternative is acceptable* to the system as a solution. In most cases, the modeler would then "relax" one or more of the modeled constraints by *increasing an upper-bound* and/or *decreasing a lower-bound*. Such alteration makes the selection of *some* solution vector easier without violating a constraint coefficient summation. However, if the system modeled (in reality) can neither reasonably nor rationally accept the relaxation of its "standards and priorities," the modeled region is declared infeasible. The modeler must then seek new potential solution alternatives to be included in the MAM framework. But if the earlier issue of the collective-exhaustiveness of the alternatives has been addressed, the system is declared insoluable.

## Cyclical Optimization and Solution Tracking

Cyclical optimization is accomplished by utilizing the $a_{ij}$ coefficients of each constraint as the $c_{ij}$ coefficients of the objective function. For a model with m-constraints, a maximum of m-executions, each with m-different sets of objective function coefficients, is possible. During any particular optimization cycle, the constraint whose coefficients form the objective function is still retained as a constraint for the determination of initial system feasibility.

Quite obviously (we hope) the reader now ponders the fact, that m-executions (or more appropriately, m-optimizations) will produce m-sets of optimal solution alternatives. That is, given a five-alternative model, with three-constraints, the resulting three cyclical optimizations could result in the solution sets:

|  | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | TOTAL |
|---|---|---|---|---|---|---|
| Cycle 1: | 0 | 0 | 1 | 0 | 1 | 2 |
| Cycle 2: | 1 | 0 | 0 | 1 | 0 | 2 |
| Cycle 3: | 0 | 1 | 0 | 0 | 0 | 1 |
| TOTAL | 1 | 1 | 1 | 1 | 1 |  |

As you can see, the first two cycles produced a solution set with two 'solutions' each; the third selecting a single alternative only. What is more interesting (though suicide-provoking in real-life) is the fact, that each alternative was choose once (and only once) throughout the three cycles executed. Which alternative(s) should then constitute the solution set?

Suppose now that a different example (and more realistic) is posited, as follows:

| | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | TOTAL |
|---|---|---|---|---|---|---|
| Cycle 1: | 1 | 0 | 0 | 1 | 1 | 3 |
| Cycle 2: | 1 | 1 | 0 | 0 | 1 | 3 |
| Cycle 3: | 0 | 0 | 1 | 1 | 1 | 3 |
| Cycle 4: | 1 | 0 | 0 | 0 | 1 | 2 |
| Cycle 5: | 0 | 0 | 1 | 1 | 1 | 3 |
| TOTAL: | 3 | 1 | 2 | 3 | 5 | |

This five-alternative, 5-constraint problem has produced a series of '3-3-3-2-3' solutions throughout the five optimization cycles. More important (for now, anyway) is the total frequency with which each alternative was selected as a member of the solution set. This framework is very close to a vote casting situation, where each of five voters can vote for a maximum of three candidates. (We guess voter #4 is as frustrated as many of us are at election time.) Candidate #5 "picked-up" a total of five votes, followd by candidates 1 and 4. Candidates 3 and 2 acquired tow and one vote(s), respectively.

Such a tallying of solution choice by constraint cycle is known as solution tracking. Each set of constraint values takes a turn at influencing the development of a solution set; at the end of which, a simple tally displays the proportion of total choice across all possible alternative choices. The novice at this point may declare that option 5 is a clear choice; and that 1 and 4 should follow suit, forming the solution set:

$$[1 \quad 0 \quad 0 \quad 1 \quad 1].$$

Depending upon the mutual exclusivity of selected alternative solutions, we chose to agree amicably or disagree violently.

## Mutual Exclusivity of Selected Alternative Solutions

We have devoted an earlier section to the importance ot formulating collectively-exhaustive alternatives (see P. ) for evaluation via the MAM framework. It was also expressed that the alternatives should overlap as little as possible (if at all); that is, the alternatives should represent clear, distinct actions -- no portion of which are included within the domain of another alternative solution being evaluated. Such distinction is known as the mutual exclusivity of defined alternatives.

It remains ironic then, to now state that some multiple alternatives problems by their very nature and substance, preclude such mutually-exclusive solutions. At this point of ambiguity, the best teacher is an example.

Consider our earlier cyclical optimization illustration in which the final composite solution vector was:

$$[x_1 \quad x_2 \quad x_3 \quad x_4 \quad x_5] = [3 \quad 1 \quad 2 \quad 3 \quad 5]$$

Now let us place this solution into context. As a policy alternative to the management of enrollment decline, you have chose to evaluate five elementary school sites for closure, based upon five a priori stated criteria. Being the intelligent and far-sighted person you are (you're welcome!), you decide to invoke the MAM framework to analyze these sites. The resulting five-cycle optimization produced the above composite vector. What is your decision?

Those of us experienced in school closures (you can tell by the scars) know, that the closing of one site may preclude a neighboring 'jeopardized' site from immediate closure, due to the transfer of students form the former to the latter school. Thus the choice of one alternative (e.g. site) may preclude the rational selection of another alterntiave. This more situation-specific illustration of a generic nonmutual-exclusiveness inherent in the problem itself, demonstrates the need for the modeler to beware.

A solution to this problem is evident, however. Choosing the 5th site for closure, the RHS-values

$$k \cdot (A_i + SD_A)$$

can be recomputed with $i = 1,\ldots,4$ (5 missing) and the problem re-executed. Of course, the enrollments of the schools neighboring the closed site would be increased via transferred students; and criteria where enrollment was a factor, recomputed. Also, site #5 would no longer be a part of the model.

Thus it is not enough, that multiple decisioning alternatives be generated distinct from one another (mutual exclusivenss, input). Moreover, the individual entries of the derived solution set must demonstrate such distinction (mutual exclusiveness, output).

## VALIDATION OF THE MULTIPLE ALTERNATIVES MODEL

As the final section of Chapter four and prior to commencing the development and implementation of the sample models to follow in Chapter eleven, it would be remiss to ignore a most critical issue of the MAM framework; tht is, "Does MAM do what is purports to do -- the manner in which it is supposed to?" Such a demand for accountability can only be responded to with a most humple (though gratifying) 'yes.'

### Model Validity and Reliability Testing

Validation of the Multiple Alternatives Model can occur only through its ability to predict performances other than performance in itself (*viz*. validity), and the degree to which modeling results (the solution vector) are consistent with purported performance (*viz*. reliability). Validating the execution and results of a mathematical decisioning model thus extends beyond the simple notion of measurement. In effect, the modeling process must demonstrate at a *minimum*:

(1) that the decision arrived at is indicative of the criteria used in the rendering of that decision; and

(2) that the criteria as a collective whole are "predictive" of the resulting decision.

For validity testing of the MAM system, the distributional characteristics of each criterion variable must be analyzed, to determine if a significant different exists between teh distribution of the criterion measuring the "selected" alternatives and the distribution representing the "non-selected" alternatives.

If the criterion measures are interval or ratio scaled, the analysis technique is simply a oneway analysis of variance procedure, where the independent variable represents whether the alternative was selected (=1) or not (=0). The results of this ANOVA procedure would determine if the partitioned criterion distribution representing the selected solution alternatives actually reflected the initial intent of the criterion constraint focus. If the criterion measures are nominal or ordinal scaled, the use of the Chi-Squared procedure (with a (0,1) independent variable) is recommended.

Reliability testing offers a new dimension to the validation of decisioning models; that is, the test of the modeled criteria's ability to predict future "choices" between multiple alternatives based upon established criteria inter-relationships. Thus in the results of a five criteria model, we ask the question:

> "To what extent to relationships between the criterion variables (constraints) exist, in order to permit a prediction of future solution decisions based solely upon these same inter-relationships?"

Instead of a single dependent (criterion) and independent (decision) variable(s), we are now (in one example) confronted with a dichotomous dependent variable (0,1; to choose or not) and five independent variables attempting simultaneously to explain a correspondence between selection and criterion alues. This is (obviously?) the protocol for employing discriminant functions analysis. Applying discriminant analysis, prediction equations (linear combinations) are developed to allow future decisions based upon the model's use of the current constraint criteria.

Validity testing thus reflects the extent to which the MAM solution vector reflects an appropriate partitioning of each of the vector's formulation. Secondly, reliability analysis illustrates the degree to which the criteria relationships are so well defined as to be predictive (collectively) of solution vector inclusion versus exclusion.

## Individual vs. Collective Criterion Impact

We have reierated many times the superior quality of the MAM system in controlling for the impact (and influence) of interactive effects. In the previous section, analysis of variance procedures were recommended to test the validity of decision modeling per individual criterion. However, the MAM framework does not exist in a criterion-vacuum, but rather supports a collective criteiron influence upon decisionmaking. The use of discriminant functions to illustrate this collective influence as a measure of reliability, is consistent with the focus and importance of interactive-effects modeling.

A more detailed investigation is required of the interactive effects by the multiple competing criteria because of the additional reliance upon cyclical optimization and the resulting composite-generated solution vector. Only through the use of predictive linear combinations, can the true "predictable" criterion impact be understood.

## Comparative Effects from Main-Effects Modeling

An earlier discussion of the use of the composite variable ranking (CVR) technique for analyzing potential solution alternatives, introduced the main-effects modeling approach to multiple alternatives. The results from the CVR procedure can be directly compared to the MAM results for overlap. Indirectly, the CVR solution vector can be utilized as the independent variable to an ANOVA procedure, or as the dependent variable to discriminant functions. The resulting statistics can then be matched against the same statistics resulting from an analysis of MAM results; and the "differential impact" per criterion, and collectively across all criteria compared.

The reader is cautioned however to remember that the CVR approach does not control for interactive effects. Thus any particular choice (solution) takes into account only the mearsures of the criterion analyzed individuallly. It is reasonable to expect then, that CVR results may produce more aggreeable ANOVA comparisons. The "proof of the pudding" however will lie in the matching of the results from the use of discriminant functions, when all criteria all taken into account simultaneously (which is also reality's demand).

## Non-Negotiable Solution Alternatives

You might ask, why go to all this trouble in order to analyze a multiple alternatives situation? Clearly, a great deal of effort is required to define the criteria, measure and input them to the model. Is it all worth it? And if so, why?

An organization's vague, ambiguous (and otherwise 'wishy-washy") approach to decisioning might lead the casual observer to believe that the resulting decision can likewise be non-specific. While this may often occur, the actions derived from the decisions will not themselves be vague (although they may be incoherent). And the results of these actions will not be ambiguous (though they may provide worthless or even disastrous). Decision making, especially in the multiple alternatives arena, is neither as easy nor as simple (non-complex) as some people lead others to believe.

Multiple alternatives decision-making can only be rationally accomplished via the use of defined criteria; and the conscious control of the criteria's competitive interaction. If you as a decision maker can accomplish this successfully while discounting the MAM framework, we are most humply impressed. However, if having read the previous pages you can now recognize the complexity of multiple alternatives decisioning, and the requirement for a structured framework in which to evaluate these alternatives -- we rest our case!

# PART II

# PRESENTATION OF A FULL FORMULATION

# CHAPTER 05

# THE CONCEPTUALIZATION STAGE

## [ Understanding the Mission as a Function of Context ]

# THE CONTEXT

The evaluation of instructional objectives, available software for instructional implementation, and compatible hardware units rank among some of the more complex decisional problems facing educational professionals today. Like the issues of selecting school sites for closure and determining potential program units for roll-back based upon declining enrollments and dwindling fiscal revenues respectively, a highly structured and premeditated evaluation technique is required in the reliable assessment of valid criteria for determining which of the vast array of instructional objectives are best addressed via which packages on what microcomputer systems. We will explore this evaluation-decisional environment more closely before presenting a means for resolving the problems associated with matching the desired instructional design to computerized hardware and software components.

## Introduction

The use of data processing technology within the educational domain has over the past several years restricted itself almost totally to such database management efforts as maintaining student and teacher personnel files, purchasing and inventory control, and other accounting/bookkeeping activities. More recently, and with the advent of affordable microcomputers for individual building-level use, electronic data processing activities have taken a firm hold of the instructional realm of the educational enterprise. This has been especially true in the such classroom-oriented activities as computer-assisted instruction (CAI) and computer-managed instruction (CMI).

Acting as the classroom teacher's adjutant, the microcomputer provides the hardware (electronic equipment) and software (actual instructional program materials) components necessary to promote a reasonably valid and reliable relay of information to the user student for the purposes of instruction, drill and evaluation (CAI). With additional sophisticated software, this electronic "right-hand person" is also able to track the performance and progress of each individual student, compare that progress with both local as well as prescribed norms, and schedule each student for either remedial, normal or enriched instructional activities based upon as assessment of the student's performance (CMI).

Since the overall cost of possessing an integral micro-system has become more reasonable over the past two-years, such standalone microcomputers as distributed by the Apple Corporation, Tandy Corporation (Radio Shack), Ohio Scientific, Texas Instruments, Pet-Commodore, and Health Kit, are becoming as commonplace as the standard ten-key adding machine was some few decades ago. And with the onslaught of hardware machines, has also come the proliferation of 'ready-made' software programs and packages available for use within the each particular system being marketed. Until recently, software designed for one system has been unusable on another system; and thus, selection of one particular microprocessor brought with it the forced acceptance of the philosophy, goals and related activities of the software supported by the particular operating system involved.

Today however, the days of system-restricted software are numbered, with software materials being coded for accessibility to many of the more popular hardware models on the market. And, as were once the textbook publishers concerned with usable workbook materials to complement their major instructional texts, their same research and development energies are now directed toward designing micro-software compatible with major hardware systems, and parallel to their more popular text-series. Available also recently, are diverse coded packages for use in the adminstrative arena of the school setting. Software packages designed to perform such school management applications as salary planning, student data recording, property management, accounting, payroll, personnel data recording, mark reporting and mailing label generation, are now available to the principal as readily as CAI and CMI packages are to the classroom teacher.

With the initial introduction of microprocessors on the educational scene, the more logical decisional sequence for selecting a machine remained in determining the utility of available software first, and then the parallel utilizability of the hardware compatible with the software chosen. Many schools nevertheless chose a reciprocal course of action -- that is, purchased a hardware unit for whatever reason, and then reviewed the availability of appropriate software for instructional and management activities -- unfortunately discovering that the more readily accessible machine was useless unless in-house software could be developed using one of the compiler languages; and also finding that few if any school personnel had the training or ability to program the required application(s).

The emerging wide-spread availability of software packages compatible to many of the more popular hardware systems on today's market, precludes many of the limitations involved in the 'chichen and egg' controversy illustrated above. However, the sophistication and regimen of today's hardware-software decisions are no less complex or complicated based upon the diversity and versatility associated with the software compatibility and hardware accessibility. In fact, the decisioning structure could be said to now be more complex, since such a wide diversity of potential choices -- mixes and matches -- are possible in the final design of a school-based data processing system utilizing the microcomputer hardware foundation.

## The MAA Situation

The optimal choices associated with matching existing and/or desireable curricular objectives and instructional activities with available CAI/CMI software, and the array of microcomputer systems compatible with the useable software -- exists as one of the more complicated applications for which the utilization of the MULTIPLE ALTERNATIVES MODEL (Wholeben, 1980a) is specifically suited. Such a multiple alternatives analysis (MAA) situation is really a combination of six underlying sub-decisional systems which integrally represent the mix-match solution required. These sub-decisional systems can be defined as:

[1] the curriculum subsystem -- that is, assessing the differential strengths of various instructional activities in providing the foundation for valid satisfaction of curricular goals and objectives, and the ultimate accomplishment of the specific concept learning desired;

[2] the program software subsystem -- that is, assessing the differential utilities associated with each of the available instructional CAI or CMI packages in promoting the instructional activities underlying the purported design and development of each individual software unit, and its emphasis upon concept introduction, activity drill and practice, and assessment of learning which results;

[3] the hardware machine subsystem -- that is, assessing the differential utilities associated with each of the available microcomputer systems, and their concurrent support of such required peripherals as CRTs, printers, disk storage units, central memory capacity, graphic plotters, and interfacing potential larger, mainframe systems;

[4] the curriculum/software subsystem -- that is, assessing the degree or extent of capability in matching some subset of the instructional goals (activities, objectives) with defined characteristics of software packages, and the ultimate accomplishment of the specific concept learning required for 'normed' performance and progress;

[5] the software/hardware subsystem -- that is, assessing the degree or extent of capability in matching some subset of the availability software packages to the operating characteristics of the various hardware systems, and assuring that the program software units defined will be compatible to the hardware units selected; and

[6] the curriculum/software/hardware subsystem -- that is, assessing the total instructional system impact associated with particular 'mixes and matches' of the three major decisional systems incorporated within the multiple alternatives analysis setting.

Thus within each of the three major systems related to curriculum, software and hardware individually, there exists a sub-MAA model inherent to the overall multiple alternatives decision to be made. We will not dwell upon the obvious, but to illustrate the concept of multiple alternatives analysis, and its reliable means in modeling this CAI-related decisional situation.

Within the curriculum subsystem, the multiple alternatives are defined by the various 'alternative' activities which might be executed to satisfy stated instructional objectives; and in turn, the 'alternative' objectives which might be satisfied in order to bring about the desired conceptual learning. The mix/match of potential solutions to this delimma is illustrated by the various combinations some activities may form with other activities in satisfying the ultimate conceptual learning demanded of the instructional subject area or grade-level defined.

The software subsystem provides a different form of mixing and matching for final solution, since different software packages may or may not complement each other -- but do portray varying measures of effectiveness, efficiency, satisfaction and cost which are internal to the individual packages themselves. Thus while a particular package may in fact promote rapid and effective learning, the cost of this same package may be an ultimate factor in precluding the software unit from forming part of the solution.

A final example of the applicability of MAA and its utility in modeling these CAI requirements can be witnessed within the software/hardware subsystem. Here, the compatibility of each individual software unit for the particular hardware (operating) system included as a potential purchase, is controlled for. As was a common mistake some few years ago, the model for evaluating the multiple alternatives involved in choosing the best match between desired learning outcomes, available software packages, and compatible hardware systems must certain assure any selected software program will be functional on the hardware system purchased.

## Initial Assumptions

As with all modeling situations, wherein some aspect of a decisional environment or milieu is to be simulated (i.e. tested for potential impact based upon expected occurrences), there exist some basal assumptions which the modeler must address, and be permitted to acknowledge in the final development of the decisional model. For the MICROPIK model, key assumptions will involve the availability of (and/or accessibility to) quantified criterion measures for comparing the various subsystem mixes of instructional activities, software and hardware, the degree to which the classroom teachers will submit to defining their courses and subject matter into specific, differentiated instructional units (observable activities), and the extent to which different instructional disciplines (mathematics, language arts, science, industrial arts, health education, etc.) can be co-terminously model (together).

The first assumption -- the availability of valid and reliable criterion measures suitable for evaluative comparison -- is integral to design of the MAA modeling framework; and therefore a sine qua non requirement for continuation with further model construction. However, these measures do not have to exist in the a priori sense to model design, but of course must be available for successful modeling execution and decision formulation. Such data gathering requirements will involve a quasi-experimental situation, in which measures of effectiveness, etc. are collected based upon observed (or perceived) performance. Since many of the criterion measures related to software and hardware will have to be assessed by the model builder, a related assumption exists that the number of software packages and hardware units for the intended modeling evaluation be limited to a set of likely candidates; and thus reduce the necessary complexity of the model to be constructed.

The second assumption, and often the most difficult to realize, is the delineation of instructional concepts and goals into a finite set of observable and performance-related instructional activities. Although the recent rebirth of demanded specificity and measured accountability for the classroom teacher via such implements as the student learning objective (SLO) in assuring the performance output associated with learning, many teachers seem reluctant to specifically identify which activites are definitively associated with which desired learning outcomes. Over the decades, the classroom teacher has evolved through such rhetoric as academic freedom and instructional autonomy into a 'not-to-be questioned' professional, with an internal code of ethics but without the presence of an external monitor. The collapse of the yearly teacher evaluation into a 20-minute observation of classroom tactics; and the absence of in-service instruction for improving the performance of the "experienced and tenured" staff person -- point to many of the failings of the educational domain as a managed and controlled environment.

To successfully model the evaluation of instructional activities against available software and hardware components however, requires that such a delineated framework of instructional objectives exist. Again, such delineation does not need to be in existence at the commencement of modeling construction -- and may proceed as the remaining parts of the model are developed.

The third and final key assumption on the part of the modeler as this CAI-related model is constructed, remains the extent to which the total instructional system (i.e. all disciplines) are modeled within the same formulation. For most purposes, it will be necessary (and acceptable) to model each discipline separately; and thus not constrain the decisional solution to be a resolution compatible to all aspects of the instructional milieu. This has many advantages as well as disadvantages; but remains a more workable format, and one which can be more easily descriptive of the particular disciplinary area.

## Projected Expectations

The MICROPIK modeler is cautioned to remember, that the resulting criterion-referenced simulation of selecting the most appropriate software and hardware mix for optimal satisfaction of pre-stated instructional objectives and pre-defined instructional activities -- due to the complexity of its structure, and the naive face validity given its processes -- will often lead the general population (administrators and teachers) to believe its results (i.e. decisions of match) as the "gospel according to MAA". Although this author certainly does not discourage such discipleship, it is reasonable and prudent to understand the output of the CAI-MAM designed system as the best-likely decision based upon the criteria defined, and the modeling formulation constructed.

Oftentimes, certain specific requirements of a particular decision will not (or can not) be sufficiently modeled (that is, incorporated within the decision model design). If the modeler recognizes this fact, no compromise to the system is realized. However, the expectations of individuals effected by their understanding (albeit rudimentary) of the modeling framework will often be impacted by such a conscious (or unconscious) omission. Many criterion references may have to be applied to the formation of the final solution after surveying the results of the model's execution based upon the criteria input. Such a subjective addition to an otherwise 'objective' model is not compromising to the model, as long as the subjective criteria is agreed-upon as valid input to the final decision; and as long as such additive processes are consistent and visible for examination.

The classroom teacher in particular, must be brought to understand the decision model as a 'best match' of multiple alternatives. Teachers are often hesitant to adopt or accept a decision which is not 'perfect' -- and therefore have some difficulty in accepting the idea of optimality in problem resolution. Nothing has provided more of a barrier to the adoption of CAI and microcomputers within the instructional setting, than exactly this feeling of CAI being 'not as good as' the flesh-and-blood teacher -- and therefore additional expenditures should be directed towards greater teacher recruitment and concomitant reduction of teacher-pupil ratios, rather than the acquisition of microcomputers and packaged software.

## Expected Difficulties

Several barriers and/or pitfalls can be expected during the initial design and formulation of the decisioning model, and during the examination of its output (modeled decisions). Some of these are model-related while others are user-related, and have been alluded to earlier in this paper.

The major, and probably most 'key' problem to be overcome by the modeler for acceptance of the MICROPIK framework, refers to the use of quantifiable measures (i.e. numbers) for measuring everything from effectiveness through perceived satisfaction, and required revenue expenditure. Mathematicians have long since given up on the critics who having claimed that 'not everything can be related to numbers', proceed to maintain that (therefore) 'nothing should be'. However, each modeling situation will not be devoid of such criticism, nor will any acceptable response or retort be useful. Obviously, all things can not be modeled in a quantitative sense -- but those that can, should not be ignored because of the conflict which may arise. Valid referencing and scaling of criteria, and their reliable measurement -- are the best (optimal) defense to the numbers-critic.

Other difficulties have been referenced in preceding sections, including the reluctance of teachers to definitively specify the relationships of activities to concepts learned (and objectives satisfied), the perception of compromise based upon optimization, and the acceptance of modeling-by-discipline rather than including the full needs and demands of the school setting -- although this last problem can often be a strong factor in the acceptance of results on the part of the individual disciplines or subject areas.

An additional difficulty to be faced by the modeler will concern itself with the concept of 'collective exhaustiveness' regarding the inclusion of criteria impacting the final solution or decision. It is a favorite technique of the modeling critic to announce, "... but what if this particular criterion had been included in the final design of the solution ... would a different decision have necessarily resulted?". The simulation design must be ready to incorporate additional criteria for re-execution of the original modeled framework; and thereby be able to detect any differential solution formulation based upon the existence of new criterion measures. And at times, the modeler must also be ready to state categorically, and be ready to defend the position, 'enough is enough'.

A final major difficulty to be faced by the modeler and the eventual acceptance of modeling results will concern: first, the validity of the criteria selected for impacted and constructing the solution, and the parallel validity of the references (sources) defined as producing these measures; and second, the reliability of the procedures utilized in gaining these required measures. Data will sometimes be available via records, other times via standardized instruments, and sometimes only through the administration of a subjectively-based opinion questionnaire. Advance planning and careful implementation of the data gathering portion of the model building sequence, will have great rewards in the end. In the same vein, nothing so completely nullifies and destroys an otherwise careful modeling effort, than the inclusion of invalid criteria or use of unreliable measurement techniques. Even though rectified, the subsequent results of the modeling solution will be viewed with distrust and non-acceptance.

# THE MODEL

Before proceeding to demonstrate a sample construction of the MICROPIK model for evaluating various software and hardware packages across desireable curricular and instructional objectives, it is necessary to examine the rudiments of the 'multiple alternatives' modeling framework in greater technical detail. The colloquial 'garbage in, garbage out' remonstrative exists as especially pertinent to the development and implementation of the MAA modeling setting. Choice of alternatives and definition of their inter-relationships, the inclusion and specific referencing of certain criteria (and the exclusion of others), and finally the control fostered by what we will come to call the "RHS vector" (the 'right-hand-side') -- will force the model to execute in a manner either consistent with the situation being simulated, or in compliance with decisions already made by policy bodies, and now requiring pooled support and accompanying data.

Before building the specific CAI-MAM model, let us now in a very brief fashion begin to view the technical workings of the modeling framework; and how it performs the intended evaluative, comparison and final selection of alternatives function.

## Introduction

The complex issue of multiple alternatives decision-making is no stranger to the educational analyst. The selection of some number of schools from a relatively large pool of potential candidates for closure is a MAM problem. Each school site represents varying measures of effectiveness, efficiency, satisfaction and expenditure for each of a number of criterion references (e.g. capacity of building, heating requirements, building age, projected enrollment change over future years, safety factors of neighborhood, and proximity of other schools and their ability to absorb transferees in the event of the first school's closure). Some of these measures will be adjudged satisfactory (or nonsatisfactory) to varying degrees, and will be comparable with other schools across the district.

However, to include one site for closure as opposed to another site means, that "good" aspects of a 'to-be-closed' school must be sacrificed in order to keep the other school operational, even though the 'to-be-kept-open' school may have certain unsatisfactory measures on the same criterion variables which the now closed school exhibited as satisfactory. Such modeling of this decisioning situation is known as interactive effects modeling (Wholeben, 1980a), and represents the necessity of constructing solutions sets which will invariably include some form of 'controlled' preference/trade-off mechanics as the various alternatives are evaluated.

The issue of complexity is also represented in the statement of the problem: to select some number of schools for closure in order to promote certain defined goals of the district; and thus to determine how many schools will be closed and which ones. Obviously, such a model must in effect be simultaneously performing these two inter-related decisions: "how many?" and "which ones?".

The determination of which program unit budgets will be decisioned for continued funding (versus deallocation) is another example of the multiple alternatives framework, and its superior contribution to the realm of accountable and criterionreferenced evaluation and decision-making (Wholeben and Sullivan, 1981). In the fiscal deallocation model, criteria represent the projected expenditures within each object cost code for each of the units under evaluation; and in addition contain perceptual measures of administrative level of expendability. Once again of course, exists the dual responsibilities for determining how many program budgets will be discontinued, and which ones -- based upon the interactive modeling effects of the various criterion weights across unit alternatives.

## The Criterion Vectors

The multiple alternatives model is simply a system of simultaneous linear inequalities and equalities which collectively represents the problem to be solved. Such an algebraic linear system is portrayed in <Figure 1>. Note how each linear combination represents a vector of values (*viz*., coefficients) which identifies the total, measureable impact to a system of the alternatives being modeled. Thus there exists a unique (normally) combination of coefficients for each of the criterion references used as input to the decisioning process. The alternatives themselves are further defined as binary variables (that is, taking on the value of either 0 or 1 (to be excluded in the final solution set, or to be included, respectively). Vector formulation for each criterion reference,

$$[\; a_{i1}x_1 \quad a_{i2}x_2 \quad a_{i3}x_3 \quad \cdots \quad a_{ij}x_j \;]$$

portraying $i$ criterion references across $j$ alternatives, will then provide a basis for measuring total impact to the system as a whole attributable to the solution set constructed. Bounds (or limits) to what is allowable as a total impact to the system are expressed as vector entries within the conditional vector (or normally named, RHS, the right-hand-side). The RHS-values are the constants of the equations and inequalities modeling the system. <Figure 2> presents a listing of the four generic types of criteria to which each model should address content validity; and <Figure 3> depicts these criterion entries as members of the modeling framework previously illustrated within Figure 1.

## The Objective or Optimality Vector

The remainder of the modeling process concerns the use of an additional vector to assist in determining from the potentially hundreds (or millions, in some exercises) of possible alternatives, that one, best mix for which the best, possible solution exists. This process is called the search for optimality, and the vector is known as the objective function (or sometimes, the cost vector). Geometrically, the objective function is a n-1 dimensional figure passing through the n-tuple space (convex) which is feasible (that is, includes all of the constraints postulated through the use of the linear equalities and inequalities) and which seeks a minimum point within the feasible region (if the goal is to minimize the impact of the objective function's values upon the system) or a maximum point within the feasible region (if the goal is to maximize the defined objective function's impact to the system as a whole).

## The Goal of MAA and MAM

Simply stated, the multiple alternatives model is a technique which seeks to construct a solution set (a vector of 1's and 0's), such that this same solution vector represents the solution of the simultaneous system, constrained by a series of competing criterion measures (vectors), and based upon the optimality demands of the objective function.

## THE MISSION

As with all complex applications of planning, design and development in the construction of systematic evaluation and decision-making models, the MICROPIK framework is built upon a delineative, deductive base. The overall goal or mission of the MICROPIK model is to formulate an evaluation and decisioning procedure, based upon the criterion-referenced assessment and comparison of various optional alternatives regarding curriculum goals, available software and compatible hardware; and to model this evaluation framework as closely as possible (i.e. simulate) with the established needs and demands of the school environment involved. In a more simple sense, "to do what needs to be done, and what the properly ordained decision-makers would do, if they only could". Sounds straight-forward enough, do you not agree?

### Mission of the MICROPIK

It is the mission of the MICROPIK modeling framework to design and develop:

> a multiple-alternatives, criterion-referenced modeling structure -- evaluating and comparing potential microcomputer instructional software and related machine hardware -- resulting in an informed decision as to which software packages and hardware units are most optimally suited for enhancing the established instructional objectives for computer-assisted (CAI) and computer-managed (CMI) instruction within the educational enterprise.

A secondary statement of mission is also possible, dealing more generally with the CAI-MAM aspect of the modeling framework, yet more specifically with the notion of decision modeling; that is, to design and develop:

> a decisioning simulation structure -- capable of incorporating the desired, potential decisioning alternatives of the major policy bodies, and the relevant, valid criteria admissable to the needed comparison of alternatives -- and in full accord with established policy, consistent practice, and mandated legal principles and individual rights.

While the primary statement of mission (above) deals more directly with the framework and constructs of the MICROPIK application of multiple alternatives analysis (MAA), the secondary mission addresses specifically the foundational constructs of the underlying multiple alternatives model (MAM) itself.

## Major Secondary Goals

As with the primary and secondary statements of mission defined in the preceding section, design and development of the MICROPIK modeling framework will encompass several delineative levels of goals, objectives, activities and tasks before the final MAM structure is ready for execution. The construction of such a systemic model is itself an exercise in implementing the usual constructs of a more generic "planning model". A developmental paradigm (roadmap or blueprint, if you wish) is essential for the controlled construction of a reliable decisioning technique; and that technique's inclusion of valid datum and algebraic relations.

Parallel to the normal (major) goals which would accompany such model construction (e.g. planning, historigraphic review, general design, field-testing, implementation, and assessment) certain secondary goals are of demonstrative important within the modeling episode; and bear illumination and clarification at this time.

The first, major secondary goal within the design and development of the MICROPIK framework, is to maintain vigilance upon the mutual-exclusiveness construct -- regarding both alternatives included for comparison, and criteria chosen for performing that comparison. Alternatives should be separate and independent (i.e. mutually-exclusive) of other alternatives within the model. This of course will not always be desireable; and at times, the modeler will seek to correlate the usefulness of one alternative based upon the parallel existence of another alternative. This would especially be true of an instructional objectives and activities model, where sequential and progressive learning and reinforcement must be available for optimal concept learning.

Parallel vigilance upon the mutual-exclusiveness of the criteria included within the modeling framework is a matter of model efficiency, rather than a source of unreliability. As in the past 'dark history' of evaluation and decision modeling, the model builder has not always maintained the highest professional standards; and has therefore constructed the model to best depict the specific decisions desired. This procedure of 'stacking the model' is not possible with the MAM framework, in terms of including a mass of 'stacked' criteria to weight intended decisions in a certain direction. However, this is a major concern when addressing the construct of criterion collective-exhaustiveness.

The next, major secondary goal within the design and development of the MICROPIK framework, is to insure the collective-exhaustiveness of both alternatives compared, and evaluative criteria utilized. Completeness or systemic totality of the modeled simulation is of primary importance; and exists as one of the most potentially compromising circumstances regarding the possible nullification of model results.

Without the collective-exhaustiveness of the multiple alternatives represented within the model, immediate criticism will be directed towards the model as not comparing 'all possible' decisional alternatives. And, even though some alternatives may be a priori determined to be a necessary part of the final solution (regardless of their attributes as measured by the criteria), these same alternatives must be included within the model in order to summarily include the impact to the system as a whole, based upon their 'forced' inclusion within the solution vector.

As mentioned above, the collective-exhaustiveness associated with the criterion-references must be a major concern of the model builder. Simply stated, if a particular criterion is not a part of the MAM framework, then neither its impact upon the various alternatives involved nor its effect upon the system as a whole can be represented and controlled. Unfortunately, the construct of collective-exhaustiveness applied to criteria is also one of the primary nemeses of the modeler. Without a doubt, demands will exist to include 'new' and 'different' criterion measures in order to survey their resulting impact to the model's decisioning process; the "... but, what if ...?" situation has been mentioned previously. Reconstruction of the model, and the related summary of new results can be very tedious, time consuming, and moreover nerve-racking for the modeler. Because of the time and expense (both fiscal as well as mental) involved, the actual independence or non-collinearity of additional criteria can often be addressed via such available techniques as parametric or non-parametric bi-variate correlation methods, and/or the use of a oneway analysis of variance procedure (to assess relative bias).

The third, major secondary goal associated with design and development, pertains to the referencing, scaling and measuring of these mutually-exclusive and collectively-exhaustive criteria. Oftentimes, a criterion will be defined (e.g. satisfaction) which defies direct, physical measure, and must therefore be referenced and measured via more synthetic techniques (e.g. opinionnaires or surveys) to obtain modeling input (Wholeben, 1980a; 1980b; Wholeben and Sullivan, 1981). In other cases, the method of scaling the sought criterion measure (that is, how quantified) will provide declarations of potential unreliability from model critics. For example, witness the ongoing controversy concerning the use of the agreement-continuum wherein proponents of the five-point:

STRONGLY                NO              STRONGLY
DISAGREE . DISAGREE . OPINION . AGREE . AGREE

continuum scale "strongly disagree" with the six-point scale:

STRONG                      MODERATE    MODERATE              STRONG
DISAGREE . DISAGREE . DISAGREE  .  AGREE  . AGREE . AGREE

whose proponents state categorically, that "everyone has some degree of opinion, no matter how small or truly uninformed".

The controversy associated with referencing of course can be often only marginally defensible by the model builder. For example, if you want to know if parents are dissatisfied with the management and instruction of their neighborhood elementary school, as a measure of potential for the site to be closed in an era of declining enrollment -- you may not wish to ask the question via a survey, "Are you satisfied with your children's school?", in a climate of potential elimination of school sites. Other 'backdoor' methods will be necessary to obtain measures of satisfaction, without pre-biasing the respondent's input.

A final, major secondary goal to be addressed within design will concern the possible, desireable weighting of some criterion measures over others. Several techniques are possible for this within the MAM framework (weighting individual vector entries, modifying the RHS-vector, and weighting various solution vectors from the solution tracking matrix of cyclic optimization). Not only must be valid and reliable technique be utilized in the event that weighting is necessary; but so also must the procedure for obtaining the direction and extent of these weights from the policy bodies be beyond reproach.

## Selected Major Milestones

As with all planning activities which include a systematic approach to design and development as well as a heavy time comittment for implementation and evaluation, several 'points of potential concern' sine qua non can be identified by the modeler. This points or decision junctures are important in that if any delay to the activities preceding the juncture is experienced, the whole process will be delayed; or in the parlance of the planning and networking theoriest, a 'bottle-neck' formed. For the reader additional understanding of the developmental aspects associated with model design and implementation, the following list of selected major milestones has been formulated.

M-01 : ACCEPTANCE OF THE MODELING ENVIRONMENT
M-02 : REVIEW OF ESTABLISHED POLICY/PROCEDURE
M-03 : DEFINITION OF CONTEXTUAL NEED/DEMAND
M-04 : STATEMENT OF MISSION/GOALS/OBJECTIVES
M-05 : FORMULATION OF ALTERNATIVES (w/ REVIEW)
M-06 : DEFINITION/REFERENCE OF CRITERIA (w/ REVIEW)
M-07 : DATA COLLECTION/SCALING (w/ REVIEW)
M-08 : EARLY FIELD-TEST OF MODEL (COMMUNICATED)
M-09 : FULL-SCALE EXECUTION OF COMPLETED MODEL
M-10 : ANALYSIS AND SUMMARY OF FINDINGS

M-11 : VALIDITY AND RELIABILITY TESTING
M-12 : PUBLIC HEARINGS (w/ FINAL REVIEW)
M-13 : SELL HOME AND LEAVE TOWN (w/o REVIEW).

This is hardly an exhaustive list; and with even a minor clarification and delineation of topic could results in several hundred milestones -- each as important as the more relevant 12 expressed in the above listing.

Finally, the 'non-planning theorist' reader must also understand, that the above milestones need not be addressed (and planned for) in an independent, separate fashion. Many facets of the modeling process take place in parallel order (as opposed to serial); and so several phases of the modeling process will be ongoing simultaneously. One of the best and most illustrative examples of such simultaneity occurs during the alternatives' development phase. As alternatives are defined and explored, the modeler will find it hard not to (in parallel) also explore the types of criteria which would be useful in evaluating the various alternatives, how these criteria might be defined, references, scaled and measured -- and even how they might be formulated within a criterion constraint vector for input into the MICROPIK decisioning model. Of course, some aspects are truly serial, and can not be performed simultaneously; for example, the serial order of the field-test versus the full-scale implementation.

We will now examine in specific detail, the illustration of the MAA and MICROPIK missions, and the implementation of their stated secondary goals.

# CHAPTER 06

# THE DEVELOPMENT STAGE

## [ Constructing Principal Modeling Components for Decision-Making ]

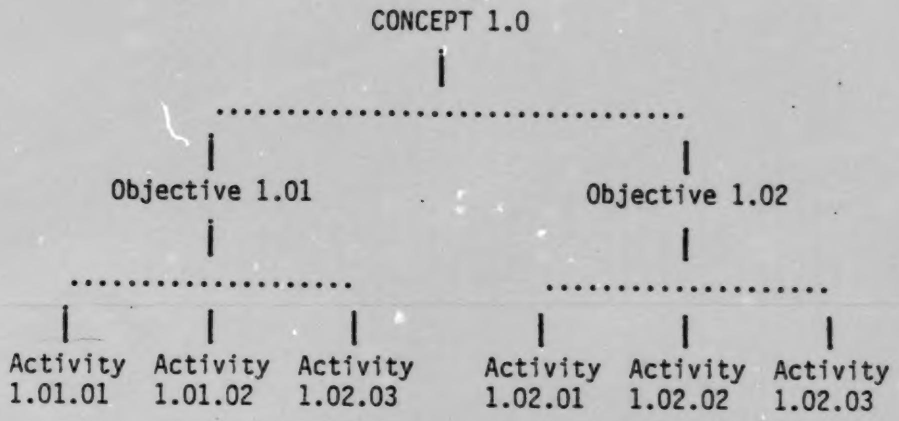
## THE ALTERNATIVES

The first major phase of MICROPIK design and development cocerns the identification, definition and development of the multiple alternatives to be evaluated by the MAA framework. The reader will recall, that the mission of this MAM-CAI modeling exercise seeks to evaluate stated curricular objectives and instructional activities (and their projected influence upon the desired degree of related concept learning), the appropriateness of available CAI/CMI program software for implementing these instructional learning exercises, and the correlated compability of existing microcomputer hardware (including peripherals) to execute the various program software packages. We will develop the alternatives-portion of the MICROPIK modeling framework within this current section; and reserve the next section for an exploration of the necessary criteria to evaluate and compare these alternatives.

The reader will also recall, that although such an evaluation of curriculum-software-hardware alternatives, and their interrelationships could very well be an end in itself, the author's over-riding concern is to posit a decisioning model by which schools and service districts will be able to make 'intelligent' decisions regarding the acquisition of computer software and hardware, and its utility in fulfilling stated computer-assisted and computer-managed instructional objectives.

### A Tri-Partite Hierarchy

As was demonstrated in the initial development of the "curriculum activity packaging" (CAP) model (Wholeben, 1980b), a MAA modeling of curriculum objectives and instructional activities as related to concept learning could be demonstrated via a delineative or hierarchical framework. Consider the usual representation of the concept-objectives-activities environ:


CONCEPT 1.0
Objective 1.01
Objective 1.02
Activity 1.01.01
Activity 1.01.02
Activity 1.02.03
Activity 1.02.01
Activity 1.02.02
Activity 1.02.03

The multiple-alternatives formulated MICROPIK model seeks to satisfy to some optimal degree, all concept and objectives-related learning as specified by curriculum requirements. The existence of multiple-alternatives for MAA evaluation exists in the formulation of the various activities "which might" be implemented in order to meet instructional (learning) needs and demands. In the MICROPIK setting therefore, all concept and objectives learning must be satisfied -- it remains the activities which will evaluated for their relative utility or appropriateness in fulfilling this required satisfaction.

In a more advanced formulation of the MICROPIK model, where objectives are to be considered alternatives available for comparitive assessment as well as the underlying activities which demonstrate the execution of the objective's intent, it is still the evaluation of the activities which will not only demonstrate their utility for inclusion within the final curriculum package, but also inductively determines whether the particular objective which defines their presence will be itself associated with the final solution set. The reader should also see therefore, that alternative 'concepts' could also be modeled in this way.

This three-level or tri-partite hierachical formulation of the multiple-alternatives structure is extremely useful to the modeler, should such defined sophistication become necessary based upon the situation being simulated. As we will see, this delineative structure within the alternatives definition will become one of the major modeling constructs to emerge from the design of the MICROPIK framework.

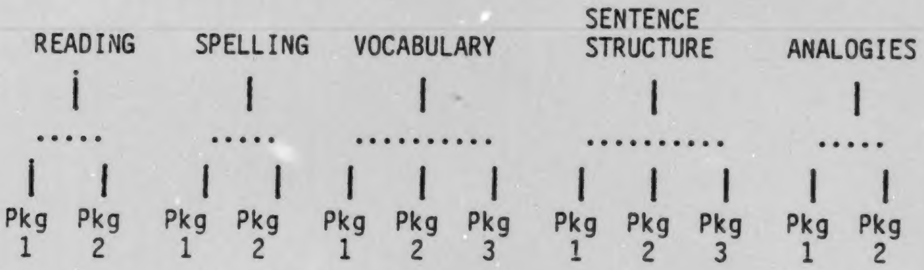
## The Sectional Alternatives Vector

Because the MICROPIK model seeks to evaluate the corresponding relationships between curriculum, software and hardware -- as well as comparisons within each of these three groups -- the structuring of modeling alternatives may be classified into the three major groups:

[1] curriculum/instructional alternatives;
[2] CAI and other program software alternatives; and
[3] hardware and peripheral(s) alternatives.

As with the tri-partite hierarchical development of the curriculum objectives and instructional activities, the design of both the software and hardware alternatives will assume a hierarchical setting.

Structuring the second section of the alternatives vector (recall that the first section refers to the curriculum entries) will be primarily concerned with different aspects of the same curricular or disciplinary framework being modeled in the first section. For example, language arts may require CAI packages which related to various types of instructions, such as: reading, spelling, vocabulary, sentence structure, and analogies. Several software packages may exist for each of the above five required areas which will summarily require evaluation both in terms of their variable values between each other (package), and in terms of their utility in addressing the stated instructional activities. The hierarchical design for this section of the alternatives vector may be constructed as:



The above seemingly bi-partite design could easily assume a more tri-partite status is difference grade-levels for CAI within the elementary school setting became a new, confounding variable for modeling within the language arts portion of the MICROPIK model.

The third and final part of the sectional alternatives vector will contain the various multiple alternatives related to the utility of various hardware machines (and their peripherals) in implementing the evaluated comparisons between the curriculum desired, and the software packages which best instruct the related instructional activities. This particular collection of hardware alternatives can be greatly simplified if the modeler in advance agrees upon 'hardware packages' for inclusion within the MICROPIK formulation. Thus, a certain model of APPLE (e.g. APPLE II PLUS), a certain type of printer, and a certain number of disk drives might become the "APPLE" package, and therefore a single alternative for comparison against the "TRS-80" package, or the "OSI" package, etc.. In comparison with the tri-partite hierarchical structure of the instructional activities, and the bi-partite structure of the software alternatives, the hardware section of the alternatives vector would become a uni-partite or single-level collection of multiple alternatives:

APPLE PACKAGE   TRS-80 PACKAGE   OSI PACKAGE   ATARI PACKAGE   TI PACKAGE ... etc.

However, should different models of the same microprocessor be required for alternatives decision-making, and should varying types of peripherals be required for inclusion within the full MAM formulation -- a tri-partite (manufacturer-model-peripheral) relationship reappears. Because some manufacturers have refused to keep their software model independent (e.g. some TRS-80 II packages will not work on the TRS-80 III; and likewise for the latest problems between APPLE II PLUS and compatibility with the APPLE III), a higher-order decision may need to be made concerning not only the type of software and peripheral required, but also the compatibility of the 'level of model' needed to execute the compatible software. The discerning reader can easily see how a quad- or even quint-partite hierarchical structure may be necessitated by such a complex multiple-alternatives setting.

## Summary

Thus the alternatives' vector for exposition of the MICROPIK model is divided into three main sections: the tri-partite curriculum section, the bi-partite software section, and finally the (hopefully) uni-partite hardware section. However the reader is cautioned regarding the true partitioning of the hardware section of the alternatives vector. It is very likely in consideration of the problems with the lack of upward-compatibility of a particular system's software, and indeed in the quality-differential between peripherals and the type of peripheral (e.g. graphics plotters), that the hardware section could easily take on quad-partite characteristics.

In summary then, the alternatives vector can be illustrated as follows:

| CURRICULUM COMPONENTS | | SOFTWARE COMPONENTS | | HARDWARE |
|---|---|---|---|---|
| ACT ACT ACT | ACT ACT... | PKG PKG | PKG PKG PKG... | PKG PKG PKG... |
| 1.1 1.2 1.3 | 2.1 2.2 | 1.1 1.2 | 2.1 2.2 2.3 | 1 2 3 |

## THE CRITERIA

To fulfill the stated premises of the MICROPIK model in determining the appropriate microcomputer hardware and software in terms of stated instructional requirements, the various sections of multiple alternatives described in the previous topic must be evaluated across various competing criteria. As was mentioned in a previous section, the MICROPIK decisioning model requires a total of six 'types' of criterion formulations: three to address the intra-relationships existent within each of the three sectional areas of curriculum, software and hardware -- to allow cross-comparisons of the various alternatives within each of the main alternatives' sections. Two additional criterion sets are required to measure those inter-relationships which will need to be controlled between the sections of curriculum versus software, and software versus hardware. It is assumed, that the third possible bi-sectional criterion set which would relate curriculum versus hardware can be based upon the trichotomous inference resulting from the first two bi-sectional comparisons. Finally, a criterion set will be reserved for an overall, tri-sectional evaluation of 'curriculum v. software v. hardware' inter-relationships.

### Generic Criterion Indices

As with all planning and development activities, the modeler will find the utilization of a 'philosophical' model most helpful in identifying and defining 'types' of criteria which may prove useful in discriminating between the multiple alternatives. This is of greater importance within the CAI-MAM framework due to the complicated relationships both between the three general alternative sections (curriculum, software and hardware) as well as within each of these general sections. Before a general listing and discussion of more specific criterion indices which will be of some benefit to the MICROPIK modeler, a more genus-oriented discussion of criterion-type will be presented.

Three categories of generic criterion indices seem to exist for all problems of evaluation and decision-making when dealing with multiple alternatives:

[1] index of contextual need based upon performance;
[2] index of relative worth or value; and
[3] index of general resource or expenditure.

The index of contextual need based upon performance is itself a relative comparison between the measured states of perceived need, current performance or use, and observed demand. Such contingencies as where demand is greater than need suggests either an unrealistic understanding of the enterprise, or an equally unrealistics understanding of the characteristics of whatever is declared 'in demand'. Of course, a contingency of need greater than demand might also point to a lack of understanding of the context within which the organization exists. Indicators such as might indicate waste (demand greater than performance and/or need) or intervention (need greater than performance) must also be addressed in some fashion as part of the contextual need set of criteria.

The index of relative worth or value is often more easily modeled into an evaluation framework due to its more 'esoteric' issues of: effectiveness, efficiency and satisfaction. To be effective, whatever is performed (or in our case, selected) must "do the job". To be efficient, the selected alternative solution must do the job as quickly as possible, and within the stated operational limits of the enterprise (or less). And to be considered satisfactory, the solution must portray 'good' feelings on the part of all parties involved; or at the least, be consistent in this regard.

The index of general resource or expenditure is a more direct relating of alternatives to those elements of capital, revenue and/or expenditure which might be required in the final implementation of the selected alternative. Such resources as: time, space, facility, personnel, cost, supplies and materials, and equipment -- will all be a potential part of this particular criterion set.

With these ideas in mind, we can now move to a more specific development of sample criterion references for the MICROPIK model.

## Identification and Definition

To explore the various criterion indicators which will be of use in evaluating the curriculum, software and hardware multiple alternatives associated with the MICROPIK framework, an outline format will be presented for the reader's perusal. This outline will examine each of three major alternative sections first, and then examine potential criteria for performing the aforementioned bi-sectional and tri-sectional comparisons.

Set 1.0 THE CURRICULUM SECTIONAL
(examining relationships both within curriculum objectives, and between the various, multiple instructional activities)

1.01 measures associated with performance, need and demand

1.01.01 perception of school personnel (administrators, teachers, students)

1.01.02 observed time spent on classroom instruction for various topics, group instruction versus individualized or remedial requirements

1.01.03 relative importance of the curriculum unit based upon district level syllabus standards

1.01.04 relative importance of the curriculum unit compared to all other required curricular units

1.02 measures associated with worth or value

1.02.01 perception of effectiveness, efficiency and satisfaction on part of classroom teachers and students, for each curriculum unit

1.02.02 perception of related worth or value of current implementation structure for each curriculum unit

1.02.03 observed measures of effectiveness as relate to learning and retention

1.02.04 observed measures of efficiency as relate to time required for different instructional strategies

1.02.05 related utility of each unit for success in the adult or occupational world-of-work

1.03 measures associated with general resource or expenditure

  1.03.01 related requirements for equipment, supplies or other materials in implementation of each unit

  1.03.02 necessary space and/or facility requirements

  1.03.03 related personnel staffing needs

  1.03.04 measure of relative impact upon other programs based upon resource allocation

  1.03.05 related costs and/or expenditures for each unit based upon text books, work books, etc.

Set 2.0 THE PROGRAM SOFTWARE SECTIONAL
(examining relationships between the various software packages available to perform computer-assisted instructional/managerial efforts)

2.01 measures relating to the availability of various CAI/CMI and other administrative software packages, and their comparative utility

  2.01.01 compiler languages

  2.01.02 word processing

  2.01.03 operating system languages

  2.01.04 data analysis programs

2.01.05 database management programs

2.01.06 management planning programs

2.01.07 time/project/personnel scheduling programs

2.01.08 accounting software

2.01.09 specific CAI/CMI courseware packages

2.01.10 CAI/CMI author pilots

2.01.11 graphics packages

2.01.12 system editors

2.01.13 information retrieval service (communications multiplexors)

2.02 measures relating to the results of sample field-tests or use by other individuals, concerning effectiveness and efficiency in presentation and drill, and related satisfaction on part of using parties

Set 3.0 THE MACHINE HARDWARE SECTIONAL
(examining relationships between the various hardware packages available for CAI/CMI and other administrative utilization)

3.01 availability of, and relative performance in executing certain desireable functions

3.01.01 mainframes

3.01.02 peripherals

3.01.03 operating system specifications

3.01.04 interface compatibility

3.01.05 networking

3.01.06 expansion

3.02 measures of system specification

3.02.01 clock speed (MHz)

3.02.02 keyboard type

3.02.03 video display
(resolution, character width and line length,
line height)

3.02.04 internal central memory

3.02.05 internal expansion

3.02.06 external expansion

3.02.07 internal baud rate

3.02.08 external interface baud rate

To perform the bi-sectional comparison which will relate the curriculum and software sections, and the software and hardware sections, the modeler is concerned with establishing tautological linkages between various parts of each section, based upon the final assessment of the criteria within those sections themselves. These linkages are of the usual, 'logic-reasoning' specification, and will basically control for the existence of (for example) a particular software package in the final solution set, if and only if: (1) the curriculum sectional presents a favorable criterion picture of the instructional activities involved; (2) the software sectional also presents a criterion-related picture which suggests the package is useful; and (obviously) (3) that such a particular software package exists. Co-relating the software and hardware sections is identical in procedure to that just described for the curriculum and software sectionals.

An additional and somewhat more complex implementation of the constructs supporting bi-sectional comparisons, exists in the utilization of 'slack' variables. Although this treatment is beyond the scope of this particular paper, it will be illustrated for the more experienced reader.

Recall the algebraic relation (inequality or equality) within the criterion vectors as they describe their measures across all of the multiple alternatives. Given that there exists some criterion measure appropriate for evaluating both curriculum sectional units and software sectional units (that is, same reference and same scaling), the measures across first the instructional activities can be summated and stored within a defined slack variable; likewise for a sum across the various software packages. Such a representation would exist as:

| Act 1.1 | Act 1.2 | Act 1.3 | Act 2.1 | Act 2.2 | Act 2.3 | Pkg 1.1 | Pkg 1.2 | Pkg 1.3 | Slk 1 | Slk 2 | RHS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{21}$ | $a_{22}$ | $a_{23}$ | | | | -1 | | $= 0$ |
| | | | | | | $p_{11}$ | $p_{12}$ | $p_{13}$ | | -1 | $= 0$ |
| | | | | | | | | | +1 | | $\geq b_a$ |
| | | | | | | | | | | +1 | $\geq b_p$ |
| | | | | | | | | | +1 | +1 | $\geq b_{12}$ |

and in this example, assumes that the measures represent a score of positive benefit to be maximized (thus the reason for the $\geq$ requirement within the algebraic inequality).

Many other possibilities exist of course for the modeling of criterion references in the comparison of multiple alternatives, but are particular to specific situations; and therefore not easily generalized. Once the reader masters the concept and constructs involved, the adaptation of the method to other settings is (normally?) straight-forward.

## Illustration of Criterion Use

Before moving on to a discussion of the various referencing, scaling and measurement techniques associated with data generation techniques for the CAI-MAM framework, it may be useful to provide a structured example of how a specific type of data might be collected and input to the MICROPIK model. The 'type' of data for this illustration is called "synthetic", because the source of its values is individual perception -- and not a physcially-rigid measurement of some kind (like for example, weight, height or age).

Synthetic measurement is nevertheless a most valid source of data for the evaluation of multiple alternatives; and therefore for input to the MAA modeling framework. These measures normally come from one of two sources, and usually must address the issue of 'measurement reliability' as a more subjective, intuitive judgement. The usual source is the survey or opinionnaire, where a respondent's perceptual judgement or opinion is sought concerning certain issues. For example, the respondent might be presented with a declarative statement concerning the issue of priority for microcomputer acquisition for an organization who is currently within a state of fiscal depression. The declarative statement might be formulated as:

> THE SCHOOL SHOULD ASSIGN A HIGHER PRIORITY TO THE ACQUISITION OF MICROCOMPUTERS, THAN TO NEW EQUIPMENT FOR THE PHYSICAL EDUCATION CURRICULUM;

and might ask the survey recipient to respond by choosing a position on the 6-point agreement continuum (where 1= strongly disagree and 6= strongly agree). As an optional procedure, the surveyer could list (for example) ten competing activites which require funding, and ask the respondent to rank-order (1,2,...,10) the activities from most important to least important (of the ten listed). Here, a '1' might represent 'most important', and a '2' represent 'least important' (relative to the ten presented). The important thing for the reader to understand (you might have already guessed)is, that the first option positions a high-value as a more positive response (i.e. positive in benefit to the acquisition of micros), while the second option posits a low-value as the more positive response (1st is best, etc.). The stated importance lies of course in the structuring of the criterion vector containing either the 1-6 or 1-10 values; and additionally in the fact that the decision-maker will discriminate between the high and low values in opposite ways depending upon the option chosen.

The second source of the synthetic measure approximates the first so closely as to beg a differentiated description. This additional synthetic 'type' describes the results of a prior, often physically reliable assessment or measure; and which now requires the 'respondent's' opinion or judgement as to whether the initial physical measure is "good enough", and to what extent. This form of measurement is often the perceptual results of a product field-test in a controlled, environmentally-related setting -- where the product is put under the same conditions as will be expected to exist under normal user conditions upon sale. While physical measures such as time, amount of work done, type of performance, and versatility or flexibility may be the physical measures, the user's perception of utility and acceptability will also prove to be very important criteria for evaluative consideration.

The following criterion references were included in a recent evaluation of microcomputer courseware by the Northwest Regional Educational Laboratory of Portland, Oregon. (For more information, see the periodical "microSIFT News", Vol. 2, No. 1, October 1981). Responses were from a panel of evaluators who tested the software, and then offered their judgement via a 4-point agreement continuum. Although the reader may wish to discuss the varying degrees of non-specificity associated with the 21-items, they remain still illustrative of the means of data generation, and the source of quantitative input to the MICROPIK model.

The "criteria for evaluation" were separated into two categories, content and instructional quality; and were presented as follows:

CONTENT

[01] The content is accurate;
[02] The content has educational value; and
[03] The content is free of race, ethnic, sex, and other stereotypes.

## INSTRUCTIONAL QUALITY

[04] The purpose of the package is well-defined;
[05] The package achieves its defined purpose;
[06] Presentation of content is clear and logical;
[07] The level of difficulty is appropriate for the target audience;
[08] Graphics/color/sound are used for appropriate instructional reasons;
[09] Use of the package is motivational;
[10] The package effectively stimulates student creativity;
[11] Feedback on student responses is effectively employed;
[12] The learner controls the rate and sequence of presentation and review;
[13] Instruction is integrated with previous student experience;
[14] Learning is generalizable to an appropriate range of situations;
[15] The user support materials are comprehensive;
[16] The user support materials are effective;
[17] Information displays are effective;
[18] Intended users can easily and independently operate the program;
[19] Teachers can easily employ the package;
[20] The program appropriately uses relevant computer capabilities; and
[21] The program is reliable in normal use.

The reader can easily witness, that the 1,2,3,4 options from the evaluator's assessment could be modeled for inclusion with the software sectional part of the MICROPIK. A criterion constraint would be constructed for each of the 21 items of judgement, and the 'mean-value' responses across all evaluators would be the the entries for each of the vector components; such that:

$$\sum_{k=1}^{K} (x_{ij}) \geq \text{MINIMUM}_i$$

for each of the i=1,...,21 criteria; across each of K-possible packages; where $x_{ij}$ is the mean response.

All criteria -- physical, synthetic or otherwise -- will be similarly modeled, and input into the MICROPIK framework.

## Reference and Source

Having identified and defined the criterion measures which will be utilized within the MICROPIK modeling of the CAI software and hardware decisioning problem, the modeler must next turn attention to determining 'what' will be measured in order to provide a quantified value based upon the construct of each of the variables or criteria defined. In this context, the 'what' of criterion measurement is known as the criterion reference -- that is, what the modeler refers to in order to obtain a valid measure of the criterion point identified. Then of course, the modeler must determine 'where' such a measure will be available and/or from 'who' if other people must be involved. The 'where' and 'who' in this context of criterion measurement is known as the criterion reference source or data-point source. References will always involve a determination of validity of the particular measure, while sources will always necessitate an analysis of reliability. The reader must recognize, that potential non-reliability can related to the people involved, the place or time of the measurement, and the procedure utilized in the measurement process -- that is, the who, where, when and how. The remaining interrogative adverbs of what and why relate more closely with the determined validity of the measured criterion point.

References may be categorized (loosely, I admit) into the three areas of: physical, definitional and synthetic. A physical reference or measure is one in which a fully acceptable tool of measurement is utilized to determine the value or weight of the reference involved. In science, degrees of temperature, miles of distance, and knots of wind velocity are acceptable determinants of their associated references (temperature, distance and wind velocity).

Definitional references are simple or complex transformations of physical measures in order to obtain a new datum to address a defined criterion which can not be measured directly. For example in the determination of school closures, a total of nine definitional criteria were designed and tested for their usefulness in discriminating between elementary school buildings in order to determine their reasonableness for operational discontinuance (Wholeben, 1980a). Three were found to adequately perform this discrimination: thermal efficiency, energy waste, and thermal utility -- by algebraically combining a particular combination of such physical measures as follows:

thermal efficiency: BTU consumption (natural gas, #2 fuel oil, and electricity), capacity and current enrollment of the sites;

energy waste: BTU consumption (natural gas, #2 fuel oil, and electricity), capacity and current enrollment of the sites, and the total dollar-expenditure for such utilities; and

thermal utility: BTU consumption (natural gas, #2 fuel oil, and electricity) and the total dollar-expenditure for such utilities.

For example, the definitional measure for energy waste resulted from the algebraic representation:

$$\left[\frac{\;\dfrac{\$\ \text{UTILITY}}{\text{BTU}}\;}{\text{CAPAC}}\right] - \left[\frac{\;\dfrac{\$\ \text{UTILITY}}{\text{BTU}}\;}{\text{ENROL}}\right]$$

We have already dealt with synthetic measures in some detail in the preceding section of this paper. Recall that synthetic measures are normally data points of perception or subjective judgement based upon personal opinion; and thus has all of the reliability problems associated with subjective bias. However, it must be reiterated, that synthetic criterion references are still very much an important 'source' of data for evaluation and decision-making. As is the case in all evaluation, the problem is seldom the intent; but too often the content and process used in carrying out that intent.

Specific criterion references for quantifying usable MICROPIK data input will generally involve the use of several procedures or tools. Measures related to the curriculum sectional must be demonstrative of not only the content and process of the various instructional activities, but also the relative importance and degree of duplication existing between these activities in the promotion of individual concept learning. Such criteria as the degree of achievement, amount of time required to implement the particular activity, and amount of retention by student will be directly related to the references of performance testing via a number of valid items or problems, clock time, and some form of longitudinal testing utilizing similar problem item, respectively. Criteria related more directly to opinion or perceptual judgement on the part of students and teachers concerning the various instructional activities will be referenced by (for example) some number of statements which describe an opinion concerning some aspect of the activity, and via a survey format gain a measure of 'degree of agreement' by the respondent with respect to the particular individual items.

Gaining responses to the same item (via survey techniques) from two different though related populations is a direct example of how synthetic measures can be transformed in a definitional composite, much as the physical illustrations earlier in this section. Given responses from both students and teachers to an identical item on two different surveys:

> "Learning how to spell using a 'spelling bee'
> is better than using the class workbook."

Obviously, high agreement on the parts of both teachers and students is preferred. However to control not only for degree of agreement to the item, but also for the criterion identified as 'degree of consistency' between teacher and student responses, the following transformation may be utilized to provide a definitional measure of consistency:

MINIMIZE | (teacher response mean) - (student response mean) |

where this formulation controls for between-groups consistency of response. A similar method for controlling the measure of consistency 'within-groups' is to utilize the standard deviations computed for each of the populations; and formulated as:

MINIMIZE | (teacher response standard deviation) |

and

MINIMIZE | (student response standard deviation ) | .

Measures of degree of achievement by students using different types of CAI software will be referenced similarly to those ideas expressed above for the instructional activities. Perceptual measures (synthetic) can also be referenced via the administration of valid questionnaires concerning feelings toward the experience of executing the various packages.

Criterion to permit the evaluation of the components of the hardware sectional will normally fall within either physical or synthetic references. Such physical references as clock speed of the CPU (central processing unit) in mega-hertz (MHz) equivalents (i.e. how many millions of cycles per second are performed), and of internal expansion capability in bytes of storage equivalents (a byte being a single character of input as defined by either an alphabetical character, a numeral (single-digit) or a special character (#,%,*)) -- provide readily understandable (?) illustrations. More subjective judgements are also possible concerning the 'esthetics' of the terminal face, or the quality of the printer. A survey format of the 'check-list' variety is a useful tool in gaining such information.

Through our addressing the issue of criterion references (that is, the 'what' of our needed criterion measure), we have paralleled the issue of reference source, or from where (whom) and how such information can be found (or be forthcoming). The data for the curriculum sectional will come from students, teachers and parents -- depending upon the type of criterion being measured. The process may involve the use of observation, a pencil-and-paper questionnaire, standardized achievement test, or a structured interview. Information for the criterion to permit comparable evaluations of the software packages will be measured in a similar fashion. Additional data for the software sectional however can also be gathered via the "dead data" technique of reviewing brochures and records, as well as the more "live data" techniques of observation and survey response.

Much of the information required to quantify the criteria of the hardware sectional will be found via the "dead data" search. Manufacturer's brochures and available technical product reports provide such reference sources. Journal articles may be also helpful; and so also the findings of such periodicals as the 'Consumer's Report'. Whatever reference and source the modeler utilizes for the generation of data points, the cautions concerning reference validity and source (procedureal) reliability must be ever present in the modeler's consciousness.

Except in more complicated MAA models related to the matching of instuctional activities to available CAI software and compatible hardware, the criterion reference for modeling both the curriculum-software and software-hardware sectional will that of 'availability' of the appropriate software package or hardware unit. The source of course will always be the manufacturer and distributor.

## Scaling and Measurement

Scaling refers to the type of numeric which will represent the measure of the defined criterion reference; and may be one of four types: nominal, ordinal, interval or ratio. The reader is referred to any standard tests and measurement, or introductory statistics text for operational definitions of these scaling types. As a summary however, the types may be distinguished as follows (apologies in advance to those measurement specialists and/or statisticians among the readers):

[1] the nominal scale is pure categorical classification measure of group distinction only; the relationship between groups is one of difference without reference to either direction or extent; examples are sex (male v. female) and minority (minority v. non-minority);

[2] the ordinal scale is one-step-up from the nominal type in that direction or order is now distinguishable for different responses or measures; however, the extent between these directional differences is unknown, and provides a classic potential for interpretative error; examples are assigned ranks and achievement grading as defined by 'excellent v. good v. fair v. poor';

[3] the interval scale is an improvement upon the ordinal type in that both direction and extent (or degree) are now distinctive under interpretation; the intervals between each of the unique measurement points are equal throughout the scale; examples are age expressed in whole years, and off-spring expressed in whole units (normally); and

[4] the ratio scale exhibits all qualities of the interval type, and in addition allows infinite divisions between

> any two points on the scale's continuum; in fact, the ratio scale is the only real continuum since it provides of the most finest of possible approximations available; for example speed expressed in cycles-per-second units.

The measure (of course) is simply the numerical quantity which results from use of the scale in determining the value of the criterion from the selected criterion reference.

The reader should note, that different measures (and often different scalings) can take place with respect to the same criterion reference -- or different references with respect to the same criterion identified. Measures such as these are often the result of a survey of opinion which attempts to gain insightful data concerning various issues of interest or aspects of current endeavor.

The MICROPIK model will accomodate any of the scaling types dependent upon the intent of measure (indentified and defined) being sought. Availability of certain software and hardware units will often be identified as a '1' (availability = yes) or a '0' (availability = no); and therefore uses a nominal scaling type for final measurement. Presenting a group of respondents with a list of instructional activities concerning the satisfaction of a specific curricular objective, and asking them to rank-order their importance in promoting the learning defined by that objective, results in the ordinally-scale measure of ranks (1 = most important, 2 = next most important, ...). The interval type of scaling is assumed with such extended continuum frameworks as the 6-point agreement continuum. And finally, the ratio scale is most usable with the more physical measurements associated with system specifications, cost of various software and/or hardware units versus the salaries of additional classroom teachers, and achievement performance measures on the part of the students.

## Design and Format

Valid criterion definitions and references, and reliable sources and measures, are of course not very useful if there exists no technique for entry in the multiple alternatives analysis model. Before discussing the formatting of measured criterion data points in such a way, that the MICROPIK model will be able to evaluate the various sectional options associated with choosing software packages and hardware units compatible with desired CAI/CMI objectives, it may be best to once again review the 'guts' of the MAM framework, and the model's criterion-referenced, decisioning-simulation needs.

Recall the design of the MAM framework as that of a matrix, where rows represent criterion measures across the various options or decisional alternatives, and columns represent the array of criterion measures for each of these decisional alternatives. We will be concerned by the 'row point-of-view', and address each row as the criterion vector of values or simply (?), the criterion constraint. Since each criterion vector (i.e. row) represents the values of a specific criterion across all alternatives, the reader can easily understand how these values will be capable of validly evaluating the various alternatives (against themselves). And, since each criterion constraint can be said to therefore constrain the solution process (i.e. arrive at a decision), each criterion vector can be thought of as an 'objective' or 'goal' of the modeling situation, in that certain limits will be placed upon the values which each criterion vector can assume (as a composite summation) before finally deciding upon a final, most optimal solution set.

Each criterion vector will be constructed to represent either a linear equality or inequality (although the inequality is often the more useful representation); and will therefore assume the general form of:

$$a_{i1} + a_{i2} + a_{i3} + \ldots a_{ij} \ ( \leq , = , \geq ) \ b_i$$

where i-criterion vectors have been constructed to evaluate the relative appropriateness of j-alternatives, and based upon a RHS-limit to the final composite (i.e. sum) of the particular i-th criterion vector of the value $b_i$. Note that $b_i$ therefore will exist as an upper-bound in the '$\leq$' inequality, a lower-bound in the '$\geq$' inequality, and an "identity' via an '=' equality.

Thus, each $a_{mn}$, for m=1,2,...,i criterion vectors across each n=1,2,...,j decisional alternatives, will represent a particular, consistent scaling of value for each of the i-criterion vectors. And, since each $b_k$, for k=1,2,...,i RHS-values, delimits the total (summed) composite which each criterion vector can assume dependent upon the solution set formulated ($x_n$ equaling either a '1' or a '0' depending upon the $x_n$'s inclusion or exclusion for the final solution set), the particular scale utilized will determine the type of objective which the particular vector is attempting to satisfy.

For the time being, let us set our total confusion aside, and attempt to examine each scaling type via the criterion constraint framework explained (?) above. For the reminder of this particular discussion, we will adopt that convention that a value of '1' for the $x_n$ decisional alternative will denote inclusion within the final solution set; and that a value of '0' will represent exclusion of that particular $x_n$ option from the final solution.

The nominally-scaled criterion constraint vector can also be called the frequency-constraint or counting-constraint vector, due to its use in controlling for the various frequency of a particular type of category within the final solution. One particular type of nominal control is that of assuring representative-bias -- that is, assuring the inclusion of certain amounts of specific types of alternatives within the final solution set. To illustrate this, consider a MICROPIK problem which has defined five software package alternatives within the software sectional, and denotes the first two as basically 'grammerically oriented' and the remaining three as 'vocabular oriented' in terms of a proposed language arts CAI curriculum. And futher assume that constraints are required in order to model the following three, separate objectives:

[1] exactly one of the grammar packages must be a member of the final solution set;

[2] not more than two of the vocabulary packages are allowed inclusion within the solution set; and

[3] at least three software packages must construct the final solution set, overall.

The resulting sub-matrix of the full constraint matrix (collection of all criterion vectors) would appear as follows:

| (Objectives) | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | | (RHS-value) |
|---|---|---|---|---|---|---|---|
| [01] | 1 | 1 | | | | (=) | 1 |
| [02] | | | 1 | 1 | 1 | ($\leq$) | 2 |
| [03] | 1 | 1 | 1 | 1 | 1 | ($\geq$) | 3 |

(can you see that the final solution set must contain exactly 3 entries? and that only a total of 3 possible, feasible solutions exist? and why additional data would be needed in order to determine the final solution?). This example emphasizes the utility and necessity of the objective function in resolving which of the three potential solution sets will in fact be the most optimal set.

The modeling characteristics of ordinally-scaled criterion constraint is an extension of the nominally-scaled constraint vector. Since the terms "mean order" and "sum of order" are examples of the premise, "You can do any thing with numbers, meaningful or not.", ordinal constraints are modeled within MICROPIK as a type of indicator-variable as would be found in the modeling of dummy variables within multivariate regression procedures. For each of the desired 'ordering points' (e.g. ranks; or those points which would be associated with 'excellent-good-fair-poor' responses), a separate criterion constraint vector must be developed in order to control the inclusion of various 'ordered' alternatives within the final solution set. Consider the MICROPIK curriculum-sectional in which two sets of four instructional-activity alternatives are to be modeled. Each set of four alternatives has been ranked by a panel of experts as to their relative importance to the successful implementation of curricular goals, assigning '1' to the most important, and '4' to the least important of the four such that the following assignments result:

| OBJECTIVE | ACT-1 | ACT-2 | ACT-3 | ACT-4 |
|---|---|---|---|---|
| 1 | 3 | 1 | 4 | 2 |
| 2 | 2 | 1 | 3 | 4 |

and must be modeled consistent with the following stated objectives:

[1] each objective must be satisfied;

[2] at least two activities from each objective set must be members of the final solution set;

[3] at least two of the final solution activities must be of rank=1;

[4] only one activity of rank=3 is allowed within the final solution; and

[5] no activities of rank=4 are to be included as final solution components.

The final modeling framework for these five objectives will include a maximum of seven constraints, but could be identically constructed with five constraints (can you see the duplication?):

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|---|---|---|---|---|
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| 2 | 2 | 1 | 3 | 4 |

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| (Objectives) | $x_{11}$ | $x_{12}$ | $x_{13}$ | $x_{14}$ | $x_{21}$ | $x_{22}$ | $x_{23}$ | $x_{24}$ | | (RHS) |
|---|---|---|---|---|---|---|---|---|---|---|
| [01.1] | 1 | 1 | 1 | 1 | | | | | ($\geq$) | 1 |
| [01.2] | | | | | 1 | 1 | 1 | 1 | ($\geq$) | 1 |
| [02.1] | 1 | 1 | 1 | 1 | | | | | ($\geq$) | 2 |
| [02.2] | | | | | 1 | 1 | 1 | 1 | ($\geq$) | 2 |
| [03.0] | | 1 | | | | 1 | | | ($\geq$) | 2 |
| [04.0] | 1 | | | | | | 1 | | ($\leq$) | 1 |
| [05.0] | | | 1 | | | | | 1 | (=) | 0 |

While intervally-scaled constraints can be modeled similarly to the ordinal type, careful preparation of the interval-based response continuum will often yield measures closely related to those of the ratio-variety, and thus permit ratio-type construction. For this reason, the following presentation will relate to both occurrences of interval and ratio measurement scaling of the criterion constraint vectors.

Unlike the previous discussion, ratio-scaled constraint entries are the actual criterion measure resulting from the data point on the criterion referenced identified. For example, in the case of a physical measure related to clock time (measured in MHz of cycles per second), a hardware sectional of five package alternatives would contain a constraint whose $a_{ij}$ entries for the particular constraint vector would be the actual, recorded MHz quantity from system specifications. As an illustration, assume these five hardware package alternatives have been evaluated on two separate criteria, the first on clock time, and the second on the mean response obtained from field-test users who responded to the item:

> "Response time for the unit was satisfactory."

utilizing a 6-point agreement continuum scale which itself assumes ratio-qualities. The tabular results of these measures were as followed:

| CRITERION | Unit-1 | Unit-2 | Unit-3 | Unit-4 | Unit-5 |
|---|---|---|---|---|---|
| "clock" | 1.2 | 0.4 | 1.7 | 0.9 | 0.1 |
| "response" | 3.5 | 2.4 | 1.6 | 3.7 | 4.7 |

and will require modeling as follows:

[1] no more than two units must be selected as solutions;

[2] the total sum of 'clock time' within the final choice of units for solution must not exceed the value $b_c$; and

[3] the total sum of 'response satisfaction' within the final choice of units must be at least the value $b_r$.

This sub-matrix related to the hardware sectional will be modeled as follows:

| (Objectives) | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | | (RHS) |
|---|---|---|---|---|---|---|---|
| [01] | 1 | 1 | 1 | 1 | 1 | ($\leq$) | 2 |
| [02] | 1.2 | .4 | 1.7 | .9 | .1 | ($\leq$) | $b_c$ |
| [03] | 3.5 | 2.4 | 1.6 | 3.7 | 4.7 | ($\geq$) | $b_r$ |

and once again illustrates the utility of the objective function which will be explored in a future section.

We will now deal more specifically with the development of the RHS-values especially needed for the successful computation of the exampled $b_c$ and $b_r$ used above; and of the various methods for controlling desired system impact.

## THE CONSTRAINTS

It was necessary within the previous section concerning criterion definition, referencing, scaling and formatting to illustrate the utility and credibility of the criterion-input to the MICROPIK model by structuring 'criterion constraint' examples. For the more experienced reader, it may now seem redundant and after-the-fact to commence a formal presentation on the ideas, structure and utility surrounding the utilization of such a vector within a mathematical modeling framework.

As we have already witnessed, the constraint vector is one of two algebraic types: either inequality or equality. This algebraic format serves to input specific criterion values of a defined criterion reference across the available alternatives into the model; and further utilizes the algebraic relational (i.e. $\leq$, =, or $\geq$) as the control over the final alternatives' selection (solution) procedure. In this section, we will examine in greater detail how this control works; and how the modeler can vary such control in order to structure a most versatile and flexible alternatives evaluation setting.

### Direction and Valence

The reader will recall, that the numerical values associated with each particular criterion reference are input to the MAM framework as coefficients of a linear inequality or equality, in the vector form:

$$[\ a_{i1} \quad a_{i2} \quad a_{i3} \quad \ldots \quad a_{ij}\ ]$$

where the i-th criterion (model objective or decision constraint) has distributed specific values across j-alternatives. In full algebraic linear form, the vector of coefficients represent a series of operands of either positive or negative values due to the actual numerical coefficient (e.g. a $+a_{ik}$ versus a $-a_{ik}$ for some k-alternative) whose linking operator is always the arithmetic operation of addition. For example:

$$a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + \ldots + a_{ij}x_j$$

where each of the $x_j$ independent variables represent the various multiple alternatives being evaluated for selection or inclusion within the final solution set. In using arithmetic addition to form a composite of the $a_{ij}$ values whose related $x_j$'s take on the value of '1' (i.e. inclusion within the solution set), we assume the coefficients to be additive, and thus representative of some summed effect of the particular criterion reference being modeled.

We have seen, that the coefficients will assume different modeling roles dependent not only upon the reference being modeled, but also upon the type of scaling which was utilized for quantifying the criterion-referenced measurement itself (i.e. nominal, ordinal, interval or ratio). In addition, the modeler must also determine exactly what effect the sum of each of the criterion vectors will represent for the problem being constructed. That is, will a larger sum of coefficients (viz., of higher value) be seen as more positive (benefit) or negative (undesireable). For example, if a survey item which seeks high agreement from respondents on the effect of each of several CAI/CMI packages upon student learning is to be input to the MICROPIK model, and the 6-point agreement continuum (where 6= strongly agree) was the response format used for data collection -- then the various software packages which will finally form the solution set should be such that they display "higher" agreement value than their evaluated companions. In this example, the sum of those criterion vector coefficients which modify the solution software alternatives will take on a larger value, since the coefficients themselves should be of higher 'agreement' weight. As we will soon see, such a criterion vector constraint will be called a 'maximizing' constraint, since the maximum sum of coefficient-values possible is desired.

To examine a different type of vector constraint, consider that criterion constraint whose coefficients represent the purported unit cost for each of the hardware packages being evaluated. Our goal of course, is to maximize all positive aspects of the packages possible while minimizing the expenditure required to obtain these same packages. In this case, the final sum of the cost coefficients would be preferably a small as possible without compromising quality and utility of the various alternatives included within the final solution; and so, the 'smaller' the sum, the better. Such a criterion vector constraint will be call a 'minimizing' constraint. And as we will soon see, a third type of constraint, the 'identity' constraint, will also be useful when exact-value sums are required from the modeling of the particular vector constraint.

## The 'Maximizing' Vector Constraint

The vector which seeks a higher-valued sum of the available evaluative coefficients modifying the potential solution alternatives is known as a maximizing-vector or maximization constraint. It is assumed, that the coefficients within the vector represent a desireable, positive influence upon the decisioning process; and that (therefore) the higher the coefficient value of any particular alternative being evaluated, the more likely that same alternative will be selected as a member of the final solution set.

To assure this desireable event, the algebraic inequality relational 'greater than or equal to' ($\geq$) is utilized to construct the criterion constraint, such that:

$$a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + \ldots + a_{ij}x_j \geq b_i$$

is the resulting inequality member of the MAM modeling framework, where the value $b_i$ is considered a lower-bound of the modeling constraint summation. That is, $b_i$ is that quantity which must be matched or surpassed by the summation of coefficients, in order for the particular $x_k$ alternative solutions to be members of the final solution set. Until some combination of $x_k$'s from the available $x_j$-alternatives can be found which will produce a sum greater than or equal to the listed $b_i$ value, the modeling framework is considered not solved; and if the combination can not be found, the problem setting is considered infeasible -- no solution is possible within the constrained decisioning setting as designed.

### The 'Minimizing' Vector Constraint

The vector which seeks a lower-valued sum of the available evaluative coefficients modifying the potential soltuion alternatives is known as a minimizing-vector or minimization constraint. It is assumed, that the coefficients within the vector represent an undesireable, negative influence upon the decisioning process; and that the lower the coefficient value of any particular alternative being evaluated, the more likely that same alternative will be selected as a member of the final solution set (assuming of course, that a low value correspondingly means low negative impact).

To minimize as much as possible the undesireable aspects of this particular criterion upon the final solution, the algebraic inequality relational 'less than or equal to' ($\leq$) is utilized to construct the criterion constraint, such that:

$$a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + \ldots a_{ij}x_j \leq b_i$$

is the resulting inequality member of the modeling framework, where the value $b_i$ now represents an upper-bound of the modeling constraint summation. That is, $b_i$ is that the highest value which the vector sum is allowed to assume -- and therefore allowing the sum to take on as low a value as possible in its formation of the final solution set. As with the maximizing vector, if such a minimum standard can not be satisfied by the summation across this particular vector, the problem is declared infeasible.

### The 'Identity' Vector Constraint

The third and final type of constraint which may be utilized within any MAA modeling setting is the identity-constraint. This vector is constructed as an algebraic equality, in the form:

$$a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + \ldots + a_{ij}x_j = b_i$$

where now the specified $b_i$ quantity is neither (or both if you want to be cantankerous) an upper or lower bound on the possible sum of the coefficients, but rather the exact quantity which that same sume must achieve for admittance of the modified alternatives into the final solution set. As we witness in a previous section, the identity constraint is very useful in controlling for the modeling of nominally-scaled criterion variables, and/or for the criterion vectors which represent the dummy (indicator) vectors of a previous ordinally-scale criterion reference. In addition, the identity-constraint is best suited for controlling for those stringent standards which impact upon the decisioning process, as might be required by affirmative action regulations, or the imposition of stratified-group comparisons.

## System Impact Control Via RHS-Bounds

Control for the construction of the final solution set is based upon the criterion coefficients which modify the multiple alternatives being evaluated for inclusion within that solution; and the value of the specific bound placed upon the linear inequalities or equalities being modeled within the MAM framework. As the criterion coefficients which modify the solution alternatives are summed for the combination of alternatives comprising the solution set (where $x_k = 1$), this arithmetic sum is compared to the $b_i$ value (RHS-bound) to assure compatibility with the desired impact sought (i.e. $\leq$, $=$, or $\geq$). When a particular set of alternatives can be found, such that:

[1] those 'maximizing' criterion vector coefficients modifying the members of the solution set produce sums which for each such criterion constraint, are greater-than-or-equal-to the established RHS-value(s);

[2] those 'minimizing' criterion vector coefficients modifying the members of that same solution set produce sums which for each such criterion constraint, are less-than-or-equal-to the established RHS-value(s); and

[3] those 'identity' criterion vector coefficients modifying those same solution alternative members produce sums which exactly display the values of their associated RHS-bounds;

then a solution exists which satisfies the established constraints placed upon the decisioning process as identified via the various criterion inequalities and equalities. Such a solution is known as 'feasible', and may or may not be the optimal (i.e. best) solution possible based upon the constraint matrix and RHS-vector. The determination of optimality is a function of an additional vector of values, known as the objective function -- which will be discussed later in this section. First however, we shall examine in more detail this issue of controlled impact and the RHS-vector.

The values of the RHS-vector are of course those bounds which when placed upon the sum of the coefficients of the various criterion constraint vectors control the selection of potential solution alternatives via upper or lower bounds, or identities. Simply stated, an upper-bound represents the highest value which is acceptable based upon the sum of 'solution' coefficients; and therefore most often represents a control for undesireable or negative effect as defined by the particular criterion vector. Similarly, a lower-bound represents the lowest value which is acceptable based upon the sum of these same 'solution' alternatives' coefficients; therefore most often represents a control for desireable of positive impact as defined by the particular criterion vector.

Such control based upon criterion vector coefficients sums is a form of generalized system impact control, in that (with the exception of the identity) the only requirement is to meet the upper and lower bound restrictions placed upon the inequalities. Because the restrictions are based upon the composite values of a summation, it is likely that the interactive-effects relationship between criterion values and solution alternatives will produce a solution set where some members may display 'less than acceptable' criterion weights on one or more criterion references.

Such a circumstance should come as no surprise to the reader, as a particular alternative's strength on several other criterion vectors may outweigh its associated weakness on a single measure. Since the vector sum will not distinguish its individual members (coefficients), this particular method of control is known as identifying impact to the system as a whole.

The reader may also need to be reminded at this point, that seldom do decisioning situations present such simplistic settings as will be remediated by solutions which are clearly full-positive in scope -- that is, have no negative by-products or effects associated with them. Complex situations will always require the conscious knowledge of both the positive and negative impacts associated with the solution(s). The decision-maker must be ready to establish the required preferences in order to perform the necessary 'secondary choices' which will be required when alternative decisions present both positive as well as negative aspects to the system; and then be prepared to acknowledge those trade-offs which are associated with the solution's related negative effects.

Specific system impact (as opposed to general) is capable of being modeled within the MAM setting, via such techniques as: selective sub-vector summations (controlling for marginal values of particular multiple alternatives), and individual single-independent-variable inequality (constraint) construction where j-inequalities would be required for modeling each of the j-alternatives for a particular criterion reference. In most cases, the modeler will be able to a priori detect if a particular alternative has a criterion measure which makes it undesireable as a solution (regardless of its other measures), and therefore can be excluded from the MAM procedure completely.

Generalized system impact (which is the preferred procedure) can itself be modified or varied in order to study the changes in the selection of potential solution alternatives. Such a technique is known as the restriction or relaxation of the RHS-values in their constraint of the decisioning process.

The restriction associated with the control of the RHS-vector over the selection of solutional alternatives is basically a procedure of placing more difficult demands upon the constraint vectors in their formulation of a final solution set. For the maximization vector, this will normally mean an increase of the lower-bound which the final coefficient sum must meet or surpass. For the minimization vector, a more restrictive environment will mean a decrease in the upper-bound which the coefficient sum must satisfy. Restriction of the RHS-values is usually executed in order to detect at what level of individual constraint control will the same solution set be constructed regardless of the reference of the objective function.

On the other hand, the relaxation of the individual RHS-values places less demand upon the constraint summations as they measure the generalized impact of particular solution sets to the sytem as a whole. For the maximization vector, a relaxed state is usually associated with a decrease in the value of the particular lower bound -- thus making the attainance of a sum more easily accomplished (and therefore more accepting of less positive impact by some alternatives). Similarly, the RHS-value related to a minimization vector will be increased in a state of relative relaxation -- allowing more negative impact to be acceptable to the final solution set. Relaxation of the RHS-values is usually executed in order to generate a diverse array of solution alternative vectors dependent upon the respective influence of different objective functions.

## The Objective Function

In additional to the criterion row vectors we have already examined as they relate to the modeling of multiple alternatives for the multiple alternatives analysis setting, another vector is necessary to force the formation of a solution set which is 'optimal' as defined by some a priori standard. Unlike the vectors of the constraint matrix, this new vector does not have an algebraic equivalent in the sense of an inequality or equality. Called the objective function, this vector provides the basis for constructing a solution set vector which not only is deemed acceptable to the criterion vector constraints of the constraint matrix, but which optimizes (maximizes or minimizes) the value of an additional vector of values or standards.

Thus, while the various constraint inequalities and equalities evaluate the multiple alternatives for the existence of a feasible solution (i.e. whether any solution is possible), the objective function vector chooses which of those alternative solution sets best (most optimally) addresses a particular issue. For example, the objective function may strive to prepare a solution within the constraints of the problem, such that: the satisfaction of the students involved as measured by their attitude is maximized; or, the additional expenditures which would be required to purchase additional equipment is minimized.

Choice of the objective function is itself a function of the overall objective(s) of the system comprising the problem area. Some modeling strategies will incorporate only a single objective function in the execution of the decision model; and others may use several in order to examine the impact upon the construction of the solution set. As we will see in the next section, the preferred technique is to utilize each of the constraint vectors serially as the objective function; and to record the differential impact to the formulation of the solution set associated with each vector's ultimate guide of the decisional process.

## Construction of the RHS-Bounds

The composition of the RHS-value will depend simultaneously upon the intent of the criterion constraint it modifies, and the type of scaling utilized in designing the criterion constraint's coefficients. We will examine each of the types of RHS-bounds by its association with scaling types. This discussion will apply to both maximization and minimization vectors (as well as in most cases, the identity vector).

Both nominally-scaled and ordinally-scaled constraints will normally be represented as 'frequency' or 'counting' coefficients, and will therefore require a RHS-value which controls for the total frequency associated with a particular criterion within the final solution set. As was discussed previously within the criterion section, potential solution alternatives can often be criterion-addressed via measurement scales which indicate distinct type or membership, rather than a arithmetically computable value of both direction and degree.

For example, consider the situation wherein the construction of the MICROPIK model requires crossreferencing of various software packages with compatible hardware units, for utilization within the implementation of CAI/CMI strategies. Five software packages are being evaluated which present instructional activities related to the mildly-handicapped, in the area of reading comprehension. Two of the packages can be implemented on one of the hardware systems available, while the remaining three software packages are compatible only to another hardware unit (which must be purchased if chosen). The problem has been designed to include the already on-line system with the evaluation of the not-yet-purchased system, in order to fairly compare the attributes of each system in relation to the potential software purchases.

For illustration, the software-hardware cross-references will exist as follows:

| HARDWARE UNITS | SOFTWARE PACKAGES |
|---|---|
| A | 1,2 |
| B | 3,4,5 |

and where an additional constraint of 'only a single hardware unit' must result as the preferred solution in terms of the hardware sectional itself.

Utilizing tautological constraint vectors as developed for the modeling of internal constraint logic subcategories for contingency allowance under specific inclusion (Wholeben, 1980a), that is:

"If A 'OR' B, Then C (possible)."

the resulting MICROPIK framework would exist as follows:

| S-1 | S-2 | S-3 | S-4 | S-5 | H-1 | H-2 | $S_a$ | $S_b$ | . | RHS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | | | | | | -1 | | = | 0 |
| | | | | | -2 | | -1 | | ≤ | 0 |
| ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | | |
| | | 1 | 1 | 1 | | | | -1 | = | 0 |
| | | | | | | -3 | | -1 | ≤ | 0 |
| ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | | |
| | | | | | 1 | 1 | | | = | 1 |

To model the situation above, it is necessary to utilize slack variables as temporary storage locations to denote whether any of the evaluated software packages were chosen by the model as acceptable to the curriculum instructional activities within the curriculum sectional (not shown). These slack or temporary storage variables are denoted above as $S_a$ and $S_b$; and will denote the selection of any of either the software 1,2 or software 3,4,5 packages, respectively. It is acknowledged, that discussion of the use of slacks (and indeed,tautologicals) is beyond the scope of this present paper. However, the reader should be somewhat aware of the potential for such manipulations of nominally-scaled criterion entries; and be able to at least rudimentally understand their utility. The third constraint subset, which relates the constraint of 'one, and only one' hardware unit is to be a member of the solution to the hardware sectional, is a more direct and easily verifiable use of the nominal-scale.

In consideration of both interval and ratio measurement scales as providing the basis for the arithmetic operations of multiplication and division -- not acceptable to the nominal or ordinal measure -- the construction of RHS values assumes a completely different perspective and rationale. Cognizant of the desire to control for 'general system impact' as opposed to specific alternatives values (allowing the model to generate internal preference and trade-off decisions), the development of RHS-values will now follow the generalized goal:

> ‹to design, formulate and quantify specific $b_i$ component entries of the RHS-vector for each modeled i-th criterion reference; such that the individual $b_i$ values establish bounds which the algebraic inequality or equality relational of the criterion vector must seek to satisfy; and where these individual $b_i$ values denote 'general system impact' as that measure which is defined as the sum of the individual

criterion measures across the potential solution alternatives being evaluated.

If we equate 'general impact' with the more arithmetic term of 'mean impact', then the goal becomes controlling the evaluation and final decision-making (selection of alternatives for membership within the solution set) via the structuring of some 'mean value' for controlling the summation of criterion values across the various potential alternatives. In general, one might think of this goal as follows:

$$a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + \dots + a_{ij}x_j \quad (\leq, =, \geq) \quad k(MN_A)$$

where:

$MN_A$ represents the mean of all $a_{ij}$ summed across all potential $x_j$ solutional alternatives; and

k is some constant factor (multiplier) of the mean($a_{ij}$) RHS-vector entry.

If in fact, our goal is to model the selection of alternative solution via the control of their 'mean impact' to the system as a whole, then the chosen mean term must equate the role of 'mean impact' to a specific numerical quantity. The value of $MN_A$ does not satisfy this need alone, since the sum across component entries will often result in a quantity greater than their computed mean value. However, if the modeler could identify some constant number which would approximate the perceived number of alternatives which would in turn reside in the solution set, then the use of the term $k(MN_A)$ would itself approximate the average impact to the system of a select k-number of solutional alternatives.

Accepting the above as a useful methodology for developing numerical quantities for describing mean system impact, a new problem arises. If in fact the $MN_A$ value will denote average impact, than a 'high outlier' of the modeled criterion distribution ($a_{ij}$) could be as large as two or three times the size of that same distribution's mean ($MN_A$). Thus the use of the term $MN_A$ alone would also bias the quantity of alternatives chosen for the solution set, since one alternative with a 2-times the mean value weight for its specific criterion value entry would add a double-factor to the final criterion constraint sum of that particular criterion vector across the selection solution alternatives. In addition, the MAM framework seeks to model average impact, which assumes preferences and trade-offs existing. The computer value $MN_A$ is an absolute quantity, with no such flexibility inherent within the structure of the arithmetic summation.

To resolve this dilemma, the use of the computed standard deviation for the specific criterion distribution is warranted. Identified as $SD_A$, the addition or subtraction of the standard deviation to (or from) the mean of the distribution -- that is, $MN_A + SD_A$ or $MN_A - SD_A$ -- provides a readibly usable technique for numerically modeling the concept of mean system impact as references each particular criterion. It remains now to address the two situations which warrants the use of addition or alternatively, the use of subtraction in developing the RHS-value.

Addition of the $SD_A$ term to the criterion vector computed $MN_A$ term is required for the existence of the interval or ratio scaled minimization ($\leq$) constraint, where the RHS-component represents an upper-bound; that is:

$$a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + \ldots + a_{ij}x_j \leq k(MN_A + SD_A).$$

Alternatively therefore, subtraction of the $SD_A$ term from the criterion vector computed $MN_A$ term is necessary when using the interval or ratio scaled maximization ($\geq$) constraint, where the RHS-component represents a lower-bound; that is:

$$a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + \ldots + a_{ij}x_j \geq k(MN_A - SD_A).$$

Recalling that the constant k represents the expected number of decisional alternatives which will be finally selected as members of the solution set, the multiplication of either the $(MN_A + SD_A)$ or $(MN_A - SD_A)$ terms by k represents the 'mean impact' to be entered into the RHS-vector for controlling the objective of that particular criterion vector constraint.

The reader may now ask how such an approximation technique could ever be useful for modeling the algebraic relational (=) of the identity constraint, since the potential of relating some specific sum to a computed flexible mean is remote. To actually model the identity relational, the decision-maker uses a matched pair of maximization and minimization constraints; and thereby attempts to double-bound the specific criterion vector's sum. Construction of the RHS-values for modeling identity constraints will obviously depend upon the specific criterion being referenced, but will nonetheless approximate the following paradigm:

$$a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + \ldots + a_{ij}x_j \leq k(MN_A + \tfrac{1}{2}SD_A)$$

$$a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + \ldots + a_{ij}x_j \geq k(MN_A - \tfrac{1}{2}SD_A)$$

where the use of the '½' factor relating to the standard deviation term is arbitrary. In general, as the particular criterion reference being modeler requires more or less convergence upon the identity of the RHS-value, the model builder will choose to use lesser or greater fractional parts of the $SD_A$ term, respectively.

## Weighting Via Co-Related Vectors

We have discussed previously how individual criterion constraints could be more or less influential upon the selection processes of the MAM framework through the restriction or relaxation of the constraint's RHS-value. Having discussed the computation of the RHS-values in the preceding topic, the reader should now be able to visualize the RHS-values; and therefore how the increase of a particular RHS component would restrict the maximization constraint while relaxing the minimization vector's process. Similarly, the decrease in a particular RHS component would thun relax the maximization constraint while restricting the process of the minimization vector. The author cautions the reader however, to employ such varied and most useful techniques only after attaining initial integer feasibility (i.e. assuring that at least one solution exists as the problem is currently constructed).

Another technique for weighting differential effects upon the final solution set membership's contribution to the measured general system impact, exists in the use of co-related vectors. This procedure requires a form of stratification of the available decisional alternatives into groups of relative impact, based upon the values for the individual criterion constraint being referenced. The general idea is to select separate alternatives as being more (or less) desireable for inclusion within the final solution set, based upon their individual criterion values. Of course, an alternative may be differentially 'desireable' due to relatively positive values on one or more criterion references, while containly correspondingly negative values on other vectors. Since this is almost always true, the construction of the co-related vector(s) for modeling weight will often require different co-related vector(s) across different constraints for the same alternative.

As an illustration, consider the problem where ten alternatives are being evaluated for determining the final solution to which alternative instructional activities will be implemented to satisfy curricular objective 'O'. A panel of expert teachers have reviewed the activities, and certified each to be of value sufficient to warrant their inclusion within the multiple alternatives modeling framework. This panel has also stated, that depending upon the criterion reference involved some alternatives are not only of more positive value but also should somehow be weighted for greater potential entry into the final solution set. To understand their position, the panel has identified three separate groups of preference (high, moderate and low) for the ten alternatives; and has for two specific criterion references segregated these ten alternatives into one of the three classes of preference as follows:

| CRITERION | O-1 | O-2 | O-3 | O-4 | O-5 | O-6 | O-7 | O-8 | O-9 | O-10 |
|---|---|---|---|---|---|---|---|---|---|---|
| -A- | 1 | 2 | 2 | 3 | 3 | 2 | 1 | 1 | 1 | 3 |
| -B- | 2 | 3 | 3 | 3 | 1 | 1 | 2 | 2 | 3 | 1 |

where a matrix-entry of '1' represents high preference, while an entry of '3' relates to correspondingly low preference. The panel also assumes that at least 6 instructional activities will be required, and prefer at least 4 of these activities be of preference factor 1 or 2 on at least one of the criterion vectors, and at least 2 of these 4 be factor 1 or 2 on both.

To illustrate the constraint matrix design, we will again call upon the use of slack variables as we did in the previous section, utilizing them as temporary storage locations for within-matrix summations. This particular example will require two of these slacks -- one for the preference indicators associated with criterion A, and the other associated with criterion B. The modeling design would then exist as follows:

| CO-RELATE | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 010 | $S_1$ | $S_2$ | | RHS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -A- | 1 | 1 | 1 | | | 1 | 1 | 1 | 1 | | -1 | | = | 0 |
| -B- | 1 | | | | 1 | 1 | 1 | 1 | | 1 | | -1 | = | 0 |
| "at least 4" | | | | | | | | | | | 1 | 1 | ≥ | 4 |
| "at least 2" | 1 | | | | | 1 | 1 | 1 | | | | | ≥ | 2 |
| "at least 6" | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | ≥ | 6 |

(What would have happened had an additional objective been required which stated "at least 4 of these activities be of preference factor 1 or 2 on both of the criterion constraints"?).

# CHAPTER 07

# THE EXECUTION STAGE

## [ Searching for Valid Solutions under Constrained Optimality ]

# THE EXECUTION

Now that the areas of theoretical intent, conceptual design, and technical development have been discussed at some length and with illustrations, it is time to explore the execution or implementation phase of MICROPIK modeling -- how to gain the required results of the model formulated, and what to do with those data elements once collected. It is beyond the scope of this paper to discuss in detail the mathematical software programs which facilitate the evaluation of the MAM framework. The more discerning reader is directed to be vigilant for an upcoming manuscript publication of the author entitled, "Multiple Alternatives Analysis for Educational Evaluation and Decision-Making," -- scheduled for release in late 1982 or early 1983.

This section will deal with the major four facets of the execution phase: cyclic optimization, the development of the solution tracking matrix, the creation of the various types of solution vectors, and criterion reference weighting techniques based upon the various iterations of the cyclical objective function. The individual post-hoc analyses (statistical or otherwise) which are recommended for the results of the MAM execution, will be examined in a succeeding section entitled 'Results'.

## Cyclic Optimization

Although the multiple alternatives modeling framework requires only a single objective function for implementation of a related multiple alternatives analysis, the suggest, preferred execution technique is to employ a cyclical optimization procedure, wherein each of the criterion vectors utilized within the constraint matrix portion of the MAM is cycled through the model sequencially as the objective function. In other words, given a problem of one hundred multiple alternatives modeled across twenty criterion constraints, the constructed model would be executed a total of twenty-times, once for each of the criterion constraints, where the objective function would be composed of those $a_{ij}$ values also existent within the particular i-th constraint.

The utility of cyclic optimization can best be witnessed in the statement of its goal:

> to generate a separate set of solution members based upon each individual criterion reference modeled within the full model, such that the selection of these members is based upon the same set of criterion constraints as modeled via criterion vectors and RHS-values, but where the objective function is varied according to the reference of the individual criterion vector entries.

For the above example therefore, a total of twenty solution sets would results, where the variability of membership would depend totally upon the utilized maximization or minimization of the particular criterion vector acting as the objective function for that execution.

Each criterion vector would of course be either maximized or minimized as relative to it respective positive or negative emphasis regarding the criterion values of its vector components. That is, the objective will always (or at least should) be to generate a solution which maximizes the positive or minimizes the negative characteristics of the associated criterion vector. There will moreover be occasions when selected criterion vectors will be both maximized and minimized (on separate runs) during the stage of cyclic optimization (see Wholeben and Sullivan, 1981).

The implication of cyclic optimality techniques within the setting of the MICROPIK model for selecting appropriate software and hardware packages in accordance to desired CAI/CMI-related instructional applications, illustrates a special case for the application of a cycling-executable procedure.

Recall the structure of the constraint matrix for the full MICROPIK model, composed of criterion references for each of the required five sectionals: curriculum, software, hardware, curriculum-software and software-hardware. Since each sectional is concerned with a sub-matrix portion of the full constraint matrix, a series of zero-submatrices or empty submatrices result. That is, when concerned with the curriculum sectional alone, the related row portions of the software and hardware alternatives' columns will be devoid of any data entry; and thus, 'empty'. Likewise for consideration of the software-hardware sectional, the associated rows of the curriculum alternatives' columns will be empty -- and therefore by convention, contain zeroes for each of the matrix cells within that particular submatrix portion. Imagine this potential problem setting as follows:

```
CURRIC  ALTER    SFTWAR  ALTER    HRDWAR  ALTER

(-sectional-)    /////////////    /////////////
/////////////    (-sectional-)    /////////////
/////////////    /////////////    (-sectional-)
(----------sectional---------)    /////////////
/////////////    (----------sectional---------)
```

where the various sectionals (or subsystems) relate data evaluation points either within or between decisional alternatives.

Since some of the criterion vectors (row-wise) will contain major segments of zero-entries (e.g. the curriculum sectional, where the software and hardware portions of the curriculum vectors will contain only 0's), use of that vector as an objective function poses the problem of how the MAM execution will interpret the large number of 0's. For example, if the criterion reference is such that the objective of optimization should be minimization, the zeros will have greater influence than the actual non-zero entries of the curriculum sectional portion of the criterion row vector. On the other hand, the objective of maximization will be somewhat more reliable in that the zero entries will not have as great an influence as the non-zero components; however, such non-influence is only conjectural, and really depends upon the inner-workings of the various vectors.

The author has developed another technique which seems to provide not only the reliability required of cyclic optimization techniques, but also assures the related validity of the non-zero criterion entries which might be used as the objective function entries. To explore use of this technique, consider the following circumstances related to the use of cyclic objective functions when the modeling framework (viz. the constraint matrix) contains numerous zero-submatrices or empty subsystems. The objective of the objective function is to provide an array of values which the MAM system can either maximize or minimize depending upon their measured criterion (positive or negative impact, respectively). Seldom will the values of the criterion vectors be numerically larger than three or four digits, since large numbers can be expressed in decimal units (234,556 dollars = 2.35 thousands of dollars) and smaller numbers (e.g. 1,2,...,6 of the agreement continuum) can be easily accomodated. Seldom also will negative numbers be required. Therefore, the discrimination between these smaller positive numbers and the value of '0' has great potential for being confounded, when the sum of vector entries is controlled by the RHS-vector entries.

However, if the value of a relatively large number (e.g. the value of 999999999) was substituted for the zero-entries associated with empty submatrices, and the remaining non-zero, valid entries left the same -- the ability to discriminate between valid non-zero entries and the simulated zero-entry of '999999999' is certainly enhanced. The true test is of course whether such conjecture will be viable under both maximized and minimized optimality. Minimization holds the the least potential for confounding effects, as the sum of entries within the objective function is attempting to attain a optimal minimum value relative to the $x_{ij}$ alternatives selected for inclusion within the solution set. If in fact, the sum of all valid, non-zero entries was still less than the simulated '999999999' (zero) entry, the chance of a '999999999' entry within the final solution set would be extremely small (and maybe impossible!).

For the case of requiring the maximization of the composed objective function (vector displaying positive impact values), the use of '999999999' will obviously be as disasterous as the use of '0' with minimization. However by multiplying the entire vector by '-1' -- that is, changing its valence structure -- the new value of '-999999999' becomes as foreign to maximization as it positive counterpart was to minimization. For the remainder of this paper, the use of a simulated '999999999' or '-999999999' vector entry to control for empty submatrices will be referred to as '*' and '-*' subvectors, respectively.

## Solution Tracking Matrices

Each full execution of the cyclic optimization technique will of course provide a solution to the problem being modeled; and therefore will denote which decisional alternatives were included as members of the solution set, and which were not (i.e. excluded).

Depending upon many factors (e.g. the degree of RHS restriction and/or relaxation; and the criterion influence of the particular criterion reference utilized as objective function), it is not uncommon to construct a variety of solution sets as a result of the various criterion vectors utilized in cyclic optimization. In some cases (in fact), a separate and distinct (unique) solution vector may result for each of the separate and unique criterion vectors, especially under a condition of relaxed RHS-values (Wholeben and Sullivan, 1981).

The attainance of unique solution vectors based upon the implementation of cyclic optimality is more than just an interesting result. Indeed, the existence of different solutions based upon different objective functions is exactly "what the doctor ordered", when demand exists to study the effect of bias upon the formulation of a particular solution. The reader should now be able to understand how three approaches to the never ending "... but, what if ..." problem can now be examined.

The first as we have explored within the criterion section deals with the introduction of new criterion references within the modeling framework; and then carefully examining the results of the varied solution formation. The second as examined in the preceding section on constraints, discussed the varied restriction and or relaxation of RHS-values as another method for analyzing the impact of criterion bias and decisioning intervention. The third technique of understanding the effect of new criterion references upon the solution set formation process is now available in the form of 'tracking' the varying solution set vectors as resulting from a cyclic optimization procedure. As we will see moreover, the use of 'solution vector tracking' goes beyond the identification and recognition of criterion impact and bias; and provides the main foundation for promoting such techniques as: the integral solution composite vector, the progressive criterion frequency vector, and the stepwise reformulation strategy for an iterative, sequential decision-making format.

In order to study the impact of cyclic objective functions, and their effect upon the formulation of a solution set vector, the construction of a solution tracking matrix is necessary. Structured as a rectangular dataset, where rows represent the array of multiple alternatives being evaluated and columns depict the individual criterion references for each of the cyclic objective functions -- cell entries are simply either 1's or 0's reflecting which alternatives were included (=1) within the final solution vector based upon the maximization or minimization of the particular criterion reference. As an illustration, consider the problem where eight alternatives have been evaluated across five criterion-referenced objective functions (i.e. the results of five separate executions of the MAM framework); the simulated results might have existed as follows:

| | C-1 | C-2 | C-3 | C-4 | C-5 | ISCV |
|---|---|---|---|---|---|---|
| A-1 | 1 | 0 | 1 | 0 | 0 | 2 |
| A-2 | 0 | 1 | 1 | 0 | 1 | 3 |
| A-3 | 1 | 0 | 0 | 1 | 0 | 2 |
| A-4 | 1 | 1 | 1 | 1 | 1 | 5 |
| A-5 | 0 | 0 | 0 | 1 | 0 | 1 |
| A-6 | 0 | 0 | 0 | 0 | 0 | 0 |
| A-7 | 1 | 0 | 0 | 0 | 0 | 1 |
| A-8 | 0 | 0 | 1 | 0 | 0 | 1 |
| PCFV: | 4 | 2 | 4 | 3 | 2 | |

where:

ISCV =: the integral solution composite vector, and represents the frequency with which each individual alternative was included within a solution set across all cyclic optimizations (i.e. the sum of the row vector); and

PCFV =: the progressive criterion frequency vector, and represents the total number of solution entries which comprise the solution vector based upon the particular criterion reference of the objective function (i.e. the sum of column vector).

Use of the solution tracking matrix not only summarizes the individual results of the cyclic optimizations, but also provides two additional and necessary ingredients for a more valid and reliable decisioning process. Summing the frequency of solution inclusion (ISCV) constructs a 'weighting' network for the various potential solution alternatives. In our example, alternative '4' with a weight of '5' inclusions has a distinct advantage over alternative '2' with a weight of '3' inclusions, or certainly alternatives '1' and '3' with weights of '2' inclusions each. The ultimate goal of course is to select the final solution set as that set of decisional factors which best models (or is modeled by) the criterion input for the evalution process. The integral solution composite vector provides the necessary data for just that evaluative need.

Summing the number of solution entries based upon the type of criterion objective function, constructs a analogical time-series mapping (or tracking) of the potential for further solution inclusion based upon a reiterative, stepwise solution reformulation technique. This summation of the column vectors (PCFV) has been found to a reliable predictor of the modeling framework's potential for generating additional decisions (solution sets) based upon the identified RHS-valued constraints (Wholeben, 1980b).

To translate the aforegoing paragraph into english, a practical illustration might be helpful. Consider the situation in which some number of schools need to be identified for potential closure according to a set of 24 agreed-upon criterion references. The use of cyclic optimization (cycling each of the 24 criterion vectors through the MAA model as objective function) is utilized, and the technique of reiterative, stepwise solution generation executed. Simply stated, this stepwise procedure will choose one and only one school for closure based upon the initial construction of the ISCV; then update those criterion vectors which will change value due to the closure of the school selected (e.g. enrollment, average walking distance, energy waste); and then re-execute in order to construct a second ISCV to determine the second school site for potential closure. Of course, the question is how many sites will require closure in order to meet the modeled district needs (constraints), and how will the modeler know when that limit has been achieved?

The 1980 (Wholeben) study on school closures found, that on successive iterations of the stepwise process, the values of the PCFV (the progressive criterion frequency vector) declined in a consistent fashion. That is, the individual sums of the column vectors decreased as each additional school was closed, and the original database progressively updated to reflect each of those closures. Obviously, the approach of such sums to the value of zero represents the inability of the school closure MAA model to select additional sites for closures; and thus interprets the goals of the district for site closure as having been satisfied.

Application of the solution tracking matrix, and its related components of integral solution composite (selection tally) and progressive criterion frequency vectors -- to the MICROPIK model and its need to select appropriate software packages and microcomputer hardware units compatible with desireable CAI/CMI instructional objectives -- presents a special case (with special problems) to the modeler in terms of data interpretation.

In the previous illustration, the value(s) of the selection tally vector were shown to be a result of summing across each row of a solution tracking matrix, where rows represented each solution alternative; and columns, each of the criterion vectors used as a cyclic objective function. With the MICROPIK model, the alternatives are split into three sectionals: curriculum, software and hardware -- representing different though obviously related decisions regarding the selection of appropriate CAI/CMI software packages and compatible hardware devices to match with a parallel selection of instructional activities whose needs can be met with these same software and hardware decisions. Having constructed the solution tracking matrix for the MICROPIK problem, the modeler in summing the decisional 1's across each of the inherent sectional rows must keep in mind, that three subsets of decision-making have been analyzed by the multiple alternatives analysis model:

[1] those curricular objectives and instructional activities which will be satisfied in the CAI/CMI mode of instruction;

[2] those curriculum software packages (i.e. courseware) which will accomodate these above selected instructional activities and curricular objectives; and

[3] the particular computer hardware devices (and peripherals) which will operationalize these

above curricular courseware packages as they satisfy the desired CAI/CMI instructional objectives.

Accordingly, the display of the MICROPIK solution tracking matrix will be better demonstrated as follows:

| | $C_C\cdots$ | $C_S\cdots$ | $C_H\cdots$ | $C_{CS}\cdots$ | $C_{SH}\cdots$ | $C_{CH}\cdots$ | $C_{CSH}\cdots$ |
|---|---|---|---|---|---|---|---|
| | (1,...) | (1,...) | (1,...) | (1,...) | (1,...) | (1,...) | (1,...) |
| $C_1$-1 | The curriculum subsection of the MICROPIK solution tracking matrix; where each of various $C_i$ curricular objectives and the related $C_i$-r instructional activities are tested for their inclusion within each of the solution vectors as formed by the cyclic $C_C$ ... $C_{CSH}$ objective functions. | | | | | | |
| $C_1$-2 | | | | | | | |
| $C_1$-3 | | | | | | | |
| · | | | | | | | |
| · | | | | | | | |
| $C_2$-1 | | | | | | | |
| $C_2$-2 | | | | | | | |
| · | | | | | | | |
| · | | | | | | | |
| $C_i$-p | | | | | | | |
| $S_1$-1 | The software subsection of the MICROPIK solution tracking matrix; where each of various $S_j$ curriculum and the related $S_j$-s courseware packages are tested for solution vector inclusion. | | | | | | |
| $S_1$-2 | | | | | | | |
| · | | | | | | | |
| · | | | | | | | |
| $S_2$-1 | | | | | | | |
| · | | | | | | | |
| · | | | | | | | |
| $S_j$-q | | | | | | | |
| $H_1$ | The hardware subsection of the MICROPIK; testing $H_k$ hardware inclusion decisions. | | | | | | |
| $H_2$ | | | | | | | |
| · | | | | | | | |
| · | | | | | | | |
| $H_k$ | | | | | | | |

where the appropriate criterion sectionals are represented as:

$[C_C]$ =: CURRICULUM SECTIONAL
$[C_S]$ =: SOFTWARE SECTIONAL
$[C_H]$ =: HARDWARE SECTIONAL
$[C_{CS}]$ =: CURRICULUM - SOFTWARE SECTIONAL
$[C_{SH}]$ =: SOFTWARE - HARDWARE SECTIONAL
$[C_{CH}]$ =: CURRICULUM - HARDWARE SECTIONAL
$[C_{CSH}]$ =: CURRICULUM - SOFTWARE - HARDWARE SECTIONAL.

The appropriate row summations across the applied cyclic objective functions will now present selection tally vectors (ISCV) for each of the three "C", "S" and "H" (curriculum, software and hardware) subsections; and thus denote the array of instructional activities which can be satisfied via the parallel inclusions of courseware and hardware devices. It is important to note also, that with the structure of the selection tally vector denoting a 'range of inclusion', the extent of satisfaction is available for modeler evaluation and decision-making.

## Solution Vectors and Stepwise Reformulations

The construction of the 'final' solution vector, as a binary representation of the "integral solution composite vector" (ISCV, or selection tally vector), is a rather straight-forward procedure in most cases. The problem usually encountered will involve the arbitrary decision to determine what degree of inclusion for any particular alternative will signal that alternative's selection as a decision (=1) or a non-decision (=0).

Consider the ISCV which has resulted from a cyclic optimization of a ten-alternative, twenty-criteria MAM execution; and may be simulated as follows:

$$[\ 02\ 07\ 04\ 09\ 11\ 18\ 00\ 15\ 06\ 12\ ]$$

where the first alternative was chosen as a solution a total of two-times, the second alternative a total of seven times, and so forth. The sixth alternative (inclusion = 18) was found to have the highest selection factor, the eighth alternative with the second highest (inclusion = 15); and the seventh alternative never entering any of the cyclic optimizations as a probable solution to the modeled problem. Based upon the range of the inclusion frequencies as shown, the final solution vector would be constructed by serially including (one at a time) each of the solution alternatives, starting with the one with the highest inclusion frequency first. Thus, the final solution vector would display serial development as follows:

$$\begin{array}{c}
[\,0\;0\;0\;0\;0\;1\;0\;0\;0\;0\,] \\
[\,0\;0\;0\;0\;0\;1\;0\;1\;0\;0\,] \\
[\,0\;0\;0\;0\;0\;1\;0\;1\;0\;1\,] \\
\cdot \\
\cdot \\
\cdot
\end{array}$$

until 'some' ultimate criterion was satisfied (e.g. minimum new equipment expenditures, maximum school sites left opened, or minimum additional bus-stop requirements).

The necessity of such a 'test-retest' procedure for final solution vector formulation stems of course from the lack of control upon solution formation by the various criteria after the maximization (or minimization) of the last criterion vector during cyclic optimization. The reader may also detect problems with the notion of 'testing-retesting' using only an 'ultimate' criterion reference -- instead of utilizing 'all' of the criteria within the original model. That is, the potential exists for the fourth serial configuration of the final binary solution vector, to satisfy the ultimate criterion (or criteria), but coterminously violate one or more of the original criterion references which were utilized within the execution of the MAM-comstructed problem. Other obvious problems might arise, where the k-th serial configuration of the solution vector violates a single criterion vector, halting serial solution construction -- and thus preventing the further development of a more optimal solution (i.e. better value on the ultimate criterion).

The final major problem with serial solution formulations exists with the existence of 'inter-dependence' between the various potential solution alternatives. For example, the closing of a particular school could logically cause a most positive effect upon a neighboring school whose own enrollment has been decreasing. The student transferees from the closed school who live within walking distance to the other school left open will obviously serve to alleviate some of the vacancy problems associated with the second site. Without taking this into consideration however, a serial construction of the final solution as described above might erroneously include that site as a site for immediate closure -- most embarassing to say the least.

To control for such invalid decisions (and unreliable decision-making), the use of a stepwise solution generation system is suggested, in lieu of the serial system discussed above. The stepwise solution technique incorporates many of the valid parts of the serial approach, but utilizes the serial system in a more sophisticated way.

Using our previous example of a simulated selection tally vector,

[ 02 07 04 09 11 18 00 15 06 12 ]

the 'stepwise approach' to constructing the final solution set would exist as follows. Since the sixth alternative (inclusion = 18) clearly outdistances its competitors, it would be chosed as the initial 'solution'; or,

[ 0 0 0 0 0 1 0 0 0 0 ]

would become the first iteration result of the final solution vector. The original MAM-framework would then be redesigned to signify the loss of alternative-six as a potential decisional alternative to be evaluated across the criterion references. In addition, those criterion references which are related by vestige of this decision (e.g. the enrollment of neighboring schools which would have to absorb the student transfers) would be recalculated to denote value changes (e.g. relationship of new enrollment to total capacity of the site, or the amount of vacancies). Having completed these recomputations, the reduced n-1 alternatives' model would then be re-executed, and a totally new solution tracking matrix constructed and selection tally vector designed.

The result of this n-1 (or nine alternatives) cyclic optimization might be simulated as follows:

[ 01 05 04 08 09 -- 00 14 05 10 ]

where alternative-six has been deleted from further consideration. As was found in the aforegoing 'serial construction' procedure, the eighth alternative (now = 14) becomes candidate for inclusion within the final binary solution vector, or:

[ 0 0 0 0 0 1 0 1 0 0 ].

Once again, the criterion vector constraint matrix is redesigned to denote the effect of choosing the eighth alternative as a solution; and the now n-2 MAM-model re-executed once again. Howver this third re-execution now results in the selection tally matrix,

[ 00 03 04 05 09 -- 00 -- 03 07 ]

where alternative-five is the third stepwise candidate for the final solution set (instead of alternative-ten as found with the serial procedure). Thus the final solution vector becomes,

[ 0 0 0 0 1 1 0 1 0 0 ],

and *not*

[ 0 0 0 0 0 1 0 1 0 1 ].

The reader is cautioned to the dangers of not subscribing to the idea of a stepwise solution strategy; and for the reasons which are hopefully very apparent above.

The use of the idea of stepwise solution generation may *not* play a primary role in the tracking of the various cyclic solutions for the MICROPIK formulation. It is reasonable for example, to expect, that only a single type or brand or computer hardware will be purchased by an individual school depending upon the results of the MICROPIK execution(s). Thus, the hardware sectional of the model would not be subject to a stepwise strategy. It is also reasonable to assume, that the software sectional results (solution vector entries) will be of such a nature, as to require only 'sight-verification' for final decision-making and selection. And if the decision-maker is satisfied with the particular degree to which each of the curricular objectives is met, the results will exist as chosen by some arbitrary selection from the tally vector's initial formulation.

However, the stepwise technique can play a most important role in the MICROPIK setting _if_ the initial selection tally vector displays the model's determination that more than a 'single type' of hardware manufacturer is required for optimal CAI/CMI implementation (e.g. both APPLE _and_ TRS-80). It is suggested in such instances, that the model be re-executed a total of two additional times -- once where the system is constrained to choose APPLE, and only APPLE as the hardware unit; and then where the system must choose TRS-80 as the single device compatible with other decisions from the courseware and activities portions. It can be expected, that the selection tally vectors with respect to the first 'two-device' solution will change based upon first the exclusion of TRS-80 as a candidate, and then secondly the exclusion of the APPLE. For the sake of review, the constraints effecting each of these suggested 'restraints' to model inclusion would exist as follows:

‹for the existence of APPLE, and only APPLE›

| APPLE | TRS-80 | ATARI | OSI | TI | ... | | RHS |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | ... | (=) | 1 |

‹for the existence of TRS-80, and only TRS-80›

| APPLE | TRS-80 | ATARI | OSI | TI | ... | | RHS |
|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 0 | ... | (=) | 1 |

where (as the reader will hopefully recall) the forced inclusion of the hardware unit will be reflected to the curriculum and software sectionals via the tautological constraints within the curriculum-hardware and software-hardware sectionals.

With each of these two re-executions, the modeler must then evaluate not only the differential extent(s) to which the new two selection tally vectors solve the originally modelled issue, but also the degree to which a forced, single-device restraint upon the implementation of a CAI/CMI strategy retards the actual satisfaction initially desired.

## Weighting Solutions Via Tracking Vectors

Although the technique of weighting particular decisions has been discussed in the previous section (see CONSTRAINTS), it seems appropriate to briefly demonstrate the potential benefits of declaring particular solutions as more important than others.

As demonstrated via the use of solution tracking matrices, a sub-matrix vector exists for each of the results of a cyclic optimization (maximization or minimization) of the individual criterion references. This sub-matrix vector, or tracking vector, demonstrates which alternatives were determined both integer feasible and optimal based upon the values of the full constraint matrix and the cyclic objective function, respectively. That is, each column vector of the solution tracking matrix shows the particular weight of that cyclic objective function's criterion reference upon the final solution (binary) constructed. As the value of the objective function changed (i.e. different criterion reference used), so often (in most cases) does the configuration of the resulting solution vector. We have found this circumstance to be especially true, where the RHS-values have been constructed in what we have previously named the 'relaxed' state -- that is, giving the solution process more 'lee-way' in selecting the best solution combination for final inclusion.

These various tracking vector results can be utilized to produce desired (or undesired) weights for the final selection tally (integral solution composite) vector. By determining the factor-weights to be used in the weighting process (e.g. identifying the base-criterion objective function, and then assigning factors of related importance to the other criterion references in the form of 2-times as important, 1.5-times as important, etc.), a weighted selection tally vector can be formulated.

Consider the following problem, where the solution tracking matrix has been formulated for the results of a five-alternative, five-criteria model:

| WEIGHT: | (2.0) | (1.5) | (1.0) | (2.0) | (3.0) | (n/wgt'd) | (wgt'd) |
|---|---|---|---|---|---|---|---|
| | C-1 | C-2 | C-3 | C-4 | C-5 | NW/ISCV | W/ISCV |
| A-1: | 1 | 1 | 0 | 0 | 1 | 3 | 6.5 |
| A-2: | 1 | 0 | 0 | 1 | 0 | 2 | 4.0 |
| A-3: | 0 | 0 | 1 | 0 | 0 | 1 | 1.0 |
| A-4: | 0 | 0 | 0 | 0 | 0 | - | - |
| A-5: | 1 | 1 | 1 | 1 | 1 | 5 | 9.5 |

where the use of weights does not change the direction of the selection tally vector, but does in fact change the ultimate degree to which each member of the tally vector is deemed of comparable value.

Now consider a different problem, where the various tracking vectors are not so demonstrative in their selection of potential solution alternatives:

| WEIGHT: | (2.0) | (1.5) | (1.0) | (2.0) | (3.0) | (n/wgt'd) | (wgt'd) |
|---|---|---|---|---|---|---|---|
|  | C-2 | C-2 | C-3 | C-4 | C-5 | NW/ISCV | W/ISCV |
| A-1: | 1 | 0 | 1 | 0 | 0 | 2 | 3.0 |
| A-2: | 0 | 1 | 1 | 0 | 0 | 2 | 2.5 |
| A-3: | 0 | 0 | 0 | 1 | 1 | 2 | 5.0 |
| A-4: | 0 | 0 | 0 | 0 | 1 | 1 | 3.0 |
| A-5: | 0 | 1 | 0 | 1 | 1 | 3 | 6.5 |

where weighting has provided a discriminant pattern for further evaluation by the modeler of the differences between the first three alternative decisions.

The reader will also note, that weighting can also take place with the MAM framework, prior to the initial execution of the model; and therefore be representative implicitly within the selection tally vector. The reader is also cautioned of the 'opportunity' for double-weighting, where weights are factored into the various criterion constraints before execution, and then utilized again as weights for each of the solution tracking vectors as described above.

Application of weighting techniques to the MICROPIK setting has obvious benefit for the evaluator and decision-making. By not weighting prior to the construction of the initial selection tally vector, the modeler has the opportunity to witness the differential effect (if any) weighting has upon membership within the solution vector(s). This is especially so, when the analyzed compatibility between activities, courseware and hardware has been determined initially without weighting; and then various weights are applied to instructional activities and/or software to note the effect upon the composite vector's structure.

However, the modeler must be extremely cautious of weighting strategies, and their impact upon tautological requirements, via the curriculum-software, software-hardware and curriculum-hardware sectionals. It is apparent, that indiscriminant weighting could not apply its effect universally across the entire MICROPIK model; and therefore not provide reliable results within the various differential selection tally vectors (weighted). For this reason, the use of 'weighted' solution tracking vectors is discouraged, except in cases where clear control over tautological cross-impacts is possible.

# CHAPTER 08

# THE SOLUTION STAGE

## [ Examining Modeled-Solution Results for Differential Decision-Making ]

# THE RESULTS

In the previous section on execution of the multiple alternatives model in general, and the MICROPIK modeling formulation in particular, we have been concerned with the generation of a variety of solution vectors which would provide the evaluator and/or decision-maker useful information for discriminating between multiple decisional alternatives as solutions to some pre-defined problem. Specifically, this problem is the conscious acquisition of CAI/CMI instructional software (i.e. courseware) and compatible hardware (i.e. micro-computers) for satisfying an array of identified curricular objectives, and their delineated instructional activities.

We have discussed in some detail (or for some of the readers, too much technical detail) the application of criterion references in the form of inequalities and equalities to the final selection of a set of decisional alternatives -- not only feasible in terms of solving (i.e. modeling the desired characteristics of) the problem, but also optimal in terms of providing the 'best solution' as defined by some one (or more) objective functions. We have then witnessed how the individual results of each solution set have been incorporated into a solution tracking matrix, the final composite solution identified, and differential weighting applied as desirable.

In this section, the concept of criterion strength will be be explored as it impacts upon the MICROPIK problem resolution. We will examine the related concepts of decision validity and decisioning reliability, and demonstrate how it can be applied to the MICROPIK setting. Finally, the use of various statistical procedures will be evaluated for their utility in providing the basis for some ultimate 'professional statement' concerning the validity of the results, and the reliability of the procedure utilized in determining these results.

## Criterion Strength and Decisioning Reliability

Evaluation and all decision-making resulting therewith, demand a high degree of accountability, visibility and responsibility. Today's complex issues require equally complex methodologies to assess both content and process of such issues, and to provide an understandable environment within which to simulate potential decisions and measure resulting effect or impact. As important moreover, is the secondary demand for providing a means for post-hoc evaluating not only the results of the simulated decisions, but also the influence (singularly as well as collectively) which the criterion references lend in making the original decisions. The clear need for the criterion-referenced decision-maker therefore is to satisfy the following five objectives:

[1] to validate the sophisticated decisioning methodologies which are so necessary for addressing complex problems -- yet so often ignored, discounted or feared;

[2] to study criterion effect upon the decisions made, and the impact which the system receives via those decisions; and thereby understand differential criterion weighting and influence -- "what" made a difference in constructing the decisions, and the varying impact resulting;

[3] to provide a high degree of visibility, and therefore accountability, to the public interests

served and affected via those decisions -- generating a milieu of trust within which the decisions, no matter how unexpected, can be trusted and accepted;

[4] to simulate the variable impact upon the decisions made by introducing additional criterion influences into the model, and thereby perform a path analysis from solution to solution as different criteria are utilized to construct each decision or solution -- satisfying the innate need of some individuals who must always ask, "... but, what if ...?"; and

[5] to permit easy and quick decisioning replication within an ever changing environment -- knowing the relationships between past successful decisions and the criteria used to construct those solutions, in order to understand the potential of future decisions based upon the new values of more current criterion measures.

Generally, the notion of criterion strength refers to the identification of those measures which in effect constructed the final decision or solution to the modeled problem; and furthermore provide a 'factor' measure of ordinal value or weight within that same group of 'solution-formation' variable measures. Specifically, criterion strength will address three fundamental questions existent within all decisioning evaluation:

[1] which criterion references most clearly defend the decisions made?

[2] to what extent are the criteria individually representative of the decisions made?

[3] how do the most discriminating criteria within this decision setting relate to each other in terms of importance and influence?.

A later part of this section will illustrate the utility of discriminant function(s) formulation for answering these questions of criterion strength, respectively, by evaluating the following rudiments of discriminant analysis:

[1] criteria included within the formation of discriminant functions -- that is, which references were 'entered' into the composition of the prepared functions;

[2] order-of-entry of each of the variables which discriminate the final solution vector; and

[3] weight (or factor strength) relationship between the standardized canonical discriminant coefficients.

Generally, the notion of decisioning reliability refers to the degree of trust which is implicit to the decision model (in this case, the "multiple alternatives model" - MAM); implicit in the sense, that the decision-maker can accept the results of such a criterion-referenced technology, both in terms of content (viz., effect of the criterion references within the model) as well as process (viz., effect of the model upon the criterion references). Specifically, decisioning reliability will address two fundamental questions existent within all decisioning evaluation:

[1] to what extent are the criteria collectively representative of the decisions made?

[2] to what extent can the defined matrix of criterion references re-predict the original binary (include v. exclude) solution?.

An additional part of this section will illustrate the utility of discriminant function(s) formulation for answering these questions of decisioning reliability, respectively, by evaluating the following charactistics of discriminant analysis:

[1] canonical correlation coefficients which offer a measure of relationship between the 'set' of discriminating criterion references and the 'set' of dummy variables which are used to represent the solution vector; and

[2] the frequency of mis-inclusions and/or mis-exclusions (or over-estimations and/or under-estimations) discovered when the classification coefficients constructed to predict a solution with the known relationships among the discriminating criterion variables, are utilized to re-predict the original dependent variable (original solution).

## Tools for Validity and Reliability Testing

To construct discriminant functions from the relationships between the model just discussed above and the resulting solutions formulated, require the use of linear vectors and combinations of vectors (matrix). Only those vector and matrix formulations most germane to this paper will be discussed below. The reader is invited to be patient until the scheduled publication of the manuscript, "Multiple Alternatives Analysis for

Educational Evaluation and Decision-Making" in late summer of 1982, for a detailed illustration of all vectors and matrice pertinent to MAM.

Solution Set Vector. In order to distinguish between alternatives included or excluded as members of the final solution to the system modeled, a vector of binary-decision representations is required, in the form:

[ 1 0 1 1 0 0 0 0 0 ... 1 ]

where '1' means that the criterion values associated with that particular x(j) will be computed to measure resulting system impact; and '0' means that the underlying criterion values will have no impact upon the system.

Selection Tally Vector. To observe the effect of each criterion reference upon construction of the system solution, a method called cyclic optimization (Wholeben, 1980a; Wholeben and Sullivan, 1981) is used. Under this regimen, the model is executed once for each unique criterion being used to constrain the model, where each unique criterion is cycled through the model as the objective function. For example, during one execution in the case of the school closure model, the intent may be be prepare a solution set whereby existing capacity of the remaining schools will be maximized; in another cycle, the model will be executed such that the schools remaining open within the district will minimize the amount of energy expended for facility heating requirements. The selection tally vector is basically a frequency summation vector, compiling the number of times each alternative was chosen as part of the solution vector, across all cyclic optimizations. Such a vector will be represented as:

[ 3 7 0 2 0 1 ... 4 ]

showing that the first alternative was selected as solution a total of *3* times, the second alternative a total of *7* times, and so forth. This vector is extremely important when the MAM procedure requires a step-wise decisioning process such as the school closure model -- evaluating a revised database after closing a single school such that the effects of closing each individual site is summarily incorporated into the next decision for determining additional site closures.

*Discriminant Criterion Inclusion Vector*. This vector simply represents another binary entry vector of 1's and 0's, signifying which particular criterion references were utilized via discriminant functions to develop the canonical classification coefficients, and the standardized canonical discriminant function coefficients.

*Discriminant Criterion Entry Vector*. This vector contains 1,2,...,k entries, where *k* criteria were utilized in the development of the discriminant functions, and the 1,2,...,k entries represent their order of entry into the discriminant formulation. Criterion variables not entered into the function(s) receive a value of '0', by convention.

*Discriminant Weighting Summary Vector*. Applying discriminant procedures to the binary solution vectors will result in the computation of standardized canonical discriminant function coefficients. These coefficients will reflect the utility of entered criterion vectors if those vectors contain standardized measures in lieu of the normal raw scores. By dividing each of the standardized canonical coefficients by the smallest of the standardized canonicals, the quotient will provide a factor of importance for each of the criteria as relative to the other criterion entered in the discriminant formulation. The discriminant weighting summary vector is a linear representation of these factors (quotients), where the minimum entry value is always '1.00' (smallest standardized coefficient divided by itself). Non-entered criterion locations receive a value of '0.00' by convention.

Other 'tools' have been referenced in the proceeding section of this paper: criterion constraint matrix, condition limits vector (RHS), objective function vector, and the cyclic optimization tracking matrix. Other formulations are currently under study by the author (e.g. the optimality weighting matrix) to investigate new relationships which may allow greater accountability and useful reliability of the multiple alternatives modeling framework.

## Criterion Strength Via The Optimality Weighting Matrix

The explicit check on procedureal (model) reliability by way of the discriminant functions (and their re-predictability of set membership), and the more implicit check on criterion validity by noting the type (which ones?) and strength (how much?) of the various criterion variables entering the discriminant analysis -- are not the sole measures of post hoc evaluation available to the MAM decision-maker. A further check on validity and reliability is afforded the modeler via the construction of the optimality weighting matrix.

The optimality weighting matrix is simply a summary of the the preponderance of each criterion-referenced variable utilized within the MAM procedure, as measured within each subset of the solution v. non-solution multiple alternatives. The measures of preponderance (direction, strength and weighting) result from the application of analysis of variance (ANOVA) procedures to each of the modeling criteria, based upon an alternative's membership in the final binary solution set. Successive ANOVA procedures can also be applied to the criteria based upon each of the results of the cyclic optimizations.

Denoting an alternative as either a member of the solution set (that is, =1) or not a member (therefore, =0), two separate data distributions can be constructed and summarily evaluated for both the statistical and magnitudinal significance(s) of their computed mean-value differences. Since this (0,1) analysis of variance procedure can be applied to each criterion reference, and for each of the cyclic optimality solution set results, a matrix format can be utilized to display, and furthermore evaluatively summarize the ANOVA results. This matrix is called the optimality weighting matrix, where each row represents the individual criterion reference modeled within the MAM framework, and where each column denotes the particular criterion-modeled cyclic maximization or minimization based upon a single criterion focus. For example, a 32-alternative and 24-criteria model would enable the composition of a 24 x 24 dimensional matrix with a total of 1056 cells (impressed?; or beleagured?). All such matrices will always be square matrices.

Each of these $m^2$ cells will be composed of the results of that particular oneway analysis of variance which utilized solution set membership (0,1) as an independent variable, and the individual criterion reference (constraint vector values) as a dependent variable. The specific statistics resulting from such a procedure which are of importance to our matrix are as follows:

[1] means of both the solution and non-solution distribution; and their individual standard deviations;

[2] the statistical significance of the set membership mean-differences; and

[3] a non-parametric check (usually the use of chi-squared) of those criterion mean-differences which result from non-ratio-scaled criterion references.

With this summary information, the evaluator or decision-maker is able to view the frequency of statistically-significant differences between the solution and non-solution sets, the direction of these differences and their conformance to initial constraint demands, the relative strength or magnitude of these differences with respect to degree of difference between the distribution means, and finally the extent to which the integral solution composite vector reflects the intent of the modeling framework -- and thus the intended solution to the original problem.

You might be thinking, that the above procedure will operate correctly for a ratio-scaled criterion variable, and also provide a check on well-constructed interval-scalings -- but not be at all useful for summarizing both the nominal and ordinal criterion vectors. And you would be most correct. Unfortunately, nominal data must be analyzed via contingency analysis procedures (or what most people call cross-tabulation or chi-squared techniques). Obviously, mean differences and standard deviations are not a function of this analysis (or even meaningful). The evaluator will substitute the statistical significance of the chi-squared statistic, and some summary of the differences between observed and expected frequencies, for the usual cell entries of the optimality weighting matrix.

The use of a non-parametric, numerically-ranked, oneway analysis of variance procedure (e.g. Kruskal-Wallis) works well for ordinally as well as interval scalings. Some readers might think the above ruminations an adroit hassle; but other than the validity and reliability test benefits of such statistical techniques, it does support the use of interval and ratio scalings as often and as completely as possible, without compromising the modeling framework.

As you might also have already guessed (or feared), the application of the optimality weighting matrix design to the MICROPIK setting is (once again) a special case.

Because of the use of sectionals (curriculum, software, etc.) in the MAM construction, subsets of criterion references exist which apply only to specific subsets of the multiple alternatives being evaluated. Therefore, some criterion vectors will apply only to the evaluation within the software sectional, while other criteria apply only to the evaluation between the software and hardware sectionals; or curriculum and software sectionals. Application of the ANOVA procedures to the various cyclic optimizations and the resulting relationships with the full criterion set within the constraint matrix, should therefore (it is suggested) be directed towards each of the sectionals, rather than a system total approach.

# THE INTERPRETATION

As we approach the end of our sojourn through the world of mathematical modeling and multiple alternatives analysis, and their role in the evaluation of potential decisions concerning the selection of microcomputer software and hardware for CAI/CMI applications, there remains the need to discuss the less-technical aspects of modeling -- albeit no less important. It is easy to become enamored with the process of the MAM framework, and its role in the MICROPIK setting, and unconsciously ignore the potential difficulties of the model -- both content and process --and their impact upon the resulting alternatives evaluated and decisions selected.

We have taken a great deal of time in exploring first the conceptualization of the multiple analysis framework, and second its application within the MICROPIK structure. This was necessary in order for the reader to fully understand the vast utility of the model as well as lend credence to the postulates presented. As one colleague stated some several weeks, "How can you possibly explain an application of your model to the CAI setting, if the general reader does not first understand the model itself?". This morning, I received his evaluation as to the utility of this paper, and its satisfaction in resolving just that issue he asked of some weeks ago. His response was, "Oh.". But was it declarative, interrogative or exclamatory?

This last section will deal with the underlying premises of the MICROPIK modeling structure, and their related positive and negative influences upon the decision-making required. We will initially examine the general utility of such a model, and the advantages to be enjoyed. In addition, some of the more common disadvantages and potential pitfalls of this model will also be discussed; and their role in arriving at erroneous conclusions. Finally, a totally unsolicited and thoroughly unbiased statement of the implications for this technique in future decision-making will be made.

## Utility of the MAA Modeling Procedure

It nearly suffices to state, that the multiple alternatives analysis framework adds to the evaluation and decision-making setting those components which often seem non-existent in the realm of educational decisioning: visibility, responsibility, accountability and credibility. In reviewing the aforegoing 114 pages of this technical paper, what specific references have been made which would allow the reader to adopt a trusting attitude towards the MAM modeling procedure in general, and the MICROPIK application specifically?

Multiple Alternatives. The responsibility of the evaluator and decision-maker is to examine feasible alternatives in resolving a dilemma, and then determine the most optimal approach to follow. The problems associated with not identifying and defining all available alternatives are well documented in situations where a solution to a particular problem was declared unobtainable. Other problems, concerned more with controlling for decision-maker bias and the likelihood of pre-arranged decisions, have also proved the utility for adopting a multiple alternatives' orientation.

Criterion References. Accountability in evaluation and decision-making is inextricably linked to the data utilized in formulating, analyzing and selecting the decisional alternatives in remediating a particular problem situation. The process invoved in identifying and defining the criteria for a required decision, the choice of datum points for correlating a criterion reference, and the measurement of these points for quantifying the necessary comparative values of these defined criteria -- lends a visibility to the evaluatoin and decision-making process which is fully open to public (and private) scrutiny and critique. Constituents may not agree with the decisions made, but they must understand the bases for these decisions, and the validity of these underlying criterion foundations.

Solution Membership. The singular, most indefensible aspect of decision-making in a multiple-alternatives environment is the determination of size and identity of the final solution set. The questions of "how many" and "which ones" must be answered in a structured, scientific sense; and as discussed above, reflect both the intent and demand of the criterion references imposed upon the decisioning framework.

Interactive Effects. Seldom does an alternative action possess such qualities as to be an obvious choice for membership within the final solution set. More often, alternatives will display positive characteristics on many criterion references, only to denote one or two negative by-products which may be undesireable to the system being modeled. The application of a main-effects modeling design allows positive attributes to cancel the displayed negative features; and thus nullifies any control over such negative impact to the system as a whole should those alternatives be selected as solutions. Interactive effects modeling on the other hand controls not only the impact of particular subsets of alternatives upon the system, but also individualizes the effect of each alternative across all of its criterion measures.

Focused Optimality. The questions associated with 'what is possible' and 'what is best' address all aspects of decision-making. The consideration of feasible alternatives, and the selection of some optimal alternative of 'all available alternatives' requires the parallel choice of an overall discriminant criterion reference. That is, once all of our demands have been met (constraints), the one, single best choice (optimal) must be found based upon some predefined point of reference (objective function). Several such points of reference (cyclic optimization) allow the decisioner to examine the impact of potential alternatives upon the environment being modeled.

Trade-Offs and Preferences. Since alternative solutions will often display both positive and negative attributes regarding their probable impact(s) to the system, decision-making must be able to reliably monitor both the direction and extent of effects to the system be remediated. While many side-effects may be undesireable, the quality of each alternative's positive characteristics must be allowed to model the desireable benefits of that alternative. Simultaneously, positive and negative characteristics must be allowed to co-exist and therefore be measureable, in order to truly model the real-world situation.

Stepwise Solution Formation. Since some aspects of any decision impacts upon other decisions which may be forthcoming, preparations must be made to control for the effect of such preceding decisions upon potential succeeding decisions which may be necessary to completely satisfy stated constraint requirements. With a criterion-referenced dataset as the basis for comparative evaluation among alternatives, the selection of a single decision will obviously effect the criterion values in some way (assuming of course, that the decision does in fact provide some degree of remediation to the system be modeled). In order to evaluate the 'remainder' of the system problem, this dataset must be updated to reflect the degree of solution already imposed by the choice of the previous decision (alternative selected). Subsequent analyses will then be able to provide a valid and reliable 'next' solution to impact upon the extent of problem 'remaining'. The final entry to the solution set is reached, when a subsequent analysis fails to detect a new member; and the last dataset update reflects system, criterion-referenced components as desired.

Simulation (Before) and Interrogation (After). The final measure of utility for the MAM formulation lies in its ability to provide both inductive and deductive reasoning mechanics to the system evaluator and decision-maker. Based upon a carefully derived set of criterion-references which are deemed representative of both the system being modeled, and alternatives which possess a varying degree of potential to resolve an identified problem within this system -- the multiple alternatives model is able to simulate the problem setting, and thus derive (*viz*., induce) the necessary solutions which reflect the demands and needs of the system. Moreover in the case where decisions have already been presumed based upon some set of criterion measures, the MAM framework is able to interrogate the problem setting, and thus derive (*viz*., deduce) the demands and needs of the system which reflect the a priori solutions made. Even in the event of a set of decisions without the benefit of an identified criterion-referenced database, reasonable criteria can be postulated and subsequently measured against the proposed solution set.

## Advantages and Disadvantages of MICROPIK

The need to test the content of decisions for validity, and the process utilized in arrived at this content for reliability, suggests the rather superfluous assertion that any technique for making decisions has its problems in addition to its laudable benefits. The MICROPIK modeling formulation is (regretably) no exception to this existential assertion.

Recall the main goals of the MICROPIK structure: to provide a criterion-referenced, multiple-alternatives decisioning model for evaluating CAI/CMI software and micro-computer hardware for its compatibility with desired curricular objectives and instructional activities. That the modeling framework as exposed within the preceding paper actually accomplishes this task, posits the main advantage of the model over any other decisioning tool known to this author. As stated within the preceding section concerning the utility of the MAM procedure in general, specific advantages are assignable to the MICROPIK framework in terms of its ability to:

[1] provide an evaluation framework for the development of a set of decisions (solution set) from a larger set of potential, multiple alternatives;

[2] utilize a criterion-referenced dataset as the basis for comparing the direction and degree of positive and negative attributes associated with each of the potential, multiple alternatives;

[3] control for the interactive effects between the measured criterion values, the various groupings (combinations and permutations) of the multiple alternatives, and their resulting impact upon the system as a whole -- and thus determine the members of the solution set in terms of "how many", and "which ones";

[4] investigate the effect of varying the optimality design for each separate execution (solution set formation) -- and thus examine sequentially the biasing factors associated with each criterion vector;

[5] *prepare* a database revision strategy for implementing a stepwise-procedure in developing the final solution set; and

[6] *simulate* the impact upon the system as a whole of potential decisions for remediation of the defined problem, as well as *interrogate* the relationship of past and/or current decisions to the agreed-upon criterion references supporting those decisions.

However, the implementation of the MICROPIK model also has a number of *disadvantages* associated with its utilization -- as therefore does the MAA model in general. These disadvantages can be encapsulated within three general headings: model-related, user-related, and equipment-related.

*Model-related disadvantages* are probably obvious to the reader at this point. The development of all possible or feasible solution alternatives, the definition of all sufficient and necessary criteria, the scaling and measurement for each coefficient entry to the criterion contraint vectors, and the conceptualization and computation of the appropriate RHS-values -- are enough to divert evaluator interest to other less-sophisticated evaluation techniques; and have been known to drive even the most adroit educational administrator to fits of manic depression.

*User-related disadvantages* are foreshadowed by the initial use of the terms 'mathematical modeling' and 'simultaneous linear inequalities', and the tendency on the part of the administrator to request immediate psychotherapy. These exist sufficient historical references to past evaluators who have utilized quantifiable evaluation techniques to maske the real missions of their endeavors, or to provide post hoc support to a priori decisions devoid of a valid criterion-referenced framework. The use of any new terminology is greeted with the criticism of "jargon"; the use of mathematical techniques with the criticism of "... not everything can be quantified ... and therefore, nothing should be ..."; and the use of sophisticated decisioning strategies and (as we will soon see) electronic computers with the criticism of "... too hard to understand ... too technical for consumption by the general public ... and therefore, not useful ...".

Equipment-related disadvantages are in reality the true insurmountable barriers to the acceptance and subsequent use of any MAM design. Although the author has on occasion (but infrequently) solved MAM problems "by hand" -- this is not the preferred technique. Therefore, the use of computers is the modeler's salvation. But to utilize these computers, specific software packages must themselves be available (or written) to correspond with the required mathematical programming algorithms needed for MAM solution. While such packages are available (e.g. IPMIXD, MPOS, EZLP, LINDO), they are not a usual software component on most computerized hardware mainframes. And unfortunately, most evaluators have not been instructed in their use, let alone their existence and utility.

Finally, the MICROPIK formularization of the general MAM model is (unfortunately though not apologetically) a complex variation of the multiple-alternatives, integer programming system. The use of alternative sectionals, and separate criteria to relate various sectionals for cross-evaluation, adds to the potential confusion and conflict on the part of the user and the public whose needs the modeler is attempting to satisfy.

Currently, the evaluation of curriculum, courseware and hardware for CAI/CMI implementation proceeds in an often undefined manner -- hardware is purchased; the existing compatible software is examined; and curricular objectives or instructional activities redesigned to fit the available courseware perogatives. In effect, the classroom teacher is 'locked-in' to a hardware device, which in turns narrows the choice of software, and thus ultimately defines the satisfaction of particular objectives. More and more, school districts are examining software first, then the hardware devices for compatibility, and so forth. While the newer trends in evaluating CAI/CMI are producing more satisfying results, the ability to control for all multiple alternative instructional activities while satisfying (to some degree) all curricular objectives, and relate these to the available courseware and hardware -- has not been possible (until MICROPIK, obviously).

## Major Pitfalls and Erroneous Conclusions

Within the consideration of advantages versus disadvantages, we a priori assumed a successful design, construction and execution of the MICROPIK model. Now however, some time must be expended in discussing the potential problems associated with the inappropriate design, invalid construction and/or unreliable execution of the modeling framework.

As has been reiterated throughout this paper, *inappropriate design* is usually associated with the exclusion of some alternatives (for whatever reason) from the modeling framework. For example, the absence of various instructional activities and their relationships to potential courseware availability will automatically preclude the model's potential in satisfying their needs. Likewise, the absence of a particular criterion from consideration will preclude the model's ability to control for that criterion's impact upon the system -- which may be positive or negative, and maybe even disasterous.

The appearance of invalid construction as a major pitfall often takes the form of problems associated with the scaling and measurement of the criterion coefficients (vector components); and is thus a secondary problem stemming from inappropriate criterion referencing. Problems will also arise based upon the criterion's measure and its utility in describing system impact based upon a row-vector summation.

Unreliable execution is a frequent problem associated with the construction of the RHS-vector, and the complex restriction versus relaxation effect these values have upon the summations of the individual criterion constraint vectors. The use of the cyclic optimization strategy also provides difficulty for the maintenance of reliability; indiscriminant maximization (or minimization) can introduce conflicting demands to the system, and produce solution sets in direct opposition to one another. In addition, compilation of the various cyclic solution vectors into a final selection tally vector (though valid) can also provide a new source of unreliability to the final determination of the actual binary solution vector.

In general however, once all of the procedureal, technique-oriented, and sequentially-defined prerequisites have been met, the major problems associated with the MICROPIK modeling situation remain: first, its interpretation for decision-making; and second, its incorporation into practice.

The interpretation of MICROPIK results must include a firm understanding of the MAM process, and its evaluation structure. This is the reason for expending the time and energy in the current development of this research paper. Individuals who accept the premises upon which the MAM technique is built, and the postulates of multiple alternatives evaluation and criterion-referenced control -- must also accept the notion of trade-off and preference structure, and optimality. A common problem has frequently been the erroneous conclusion, that the model's decision concerning solution membership is devoid of any negative impact. Other misinterpretations surround the idea of 'what was the problem as defined (?)', and therefore does the solution truly solve the problem, or merely cope with the actual problem's negative impact. For example, closing schools does not solve the problem of declining enrollment, but does permit a rational and accountable means of coping with its effects. Successful execution of the MICROPIK model will provide the best fit of courseware and hardware with desired activities -- but may not be able to meet all of the desired needs. A limitation of a single hardware device, and a particular preponderance of courseware on a particular hardware unit, may require the sacrifice of a single discipline's CAI requirements due to non-compatible software on the preponderant device chosen.

The incorporation of MICROPIK results into practice must never be the result of solely following the binary indicators of the final solution set vector. The modeler must recall, that the membership of the solution vector resulted from a mathematical analysis of a number of criterion-oriented inequalities, which themselves were products of definition, referencing, scaling and measurement -- and therefore all of the problems associated therein. The decision-maker must look upon the MICROPIK results as structured, controlled "suggestions"; and in many cases, just further "input" to the decisioning process which always rests in final form with a flesh and blood person. Contrary to public, wide-spread predictions of doom, technology will never replace the human decision-maker -- although the potential is there to make that decision-maker more valid, reliable and honest.

## Implications for Future Application

In closing this most laborious but very satisfying project, the forthcoming criticism from individuals who believe nothing (or at least, choose not to) unless it is accompanied with reams of data print-outs, must be addressed, and their concerns fully acknowledged.

A full piloting or field-test of the MICROPIK model, and its resulting effectiveness and efficiency in selecting micrcomputer hardware, compatible instructional software (i.e. courseware), and related CAI/CMI curricular objectives and instructional activities -- has as of the date of this paper not been accomplished. In fact, the author is currently developing a greater diversification of criterion needs and references for input to the model. Field-testing of the model is currently scheduled for the autumn of 1982; and is expected to involve a large number of school districts in order to obtain sufficient frequencies of observation to afford the necessary cross-comparisons between model types, and supported software packages. It is also the intent of this author, to involve each of the major hardware and software distributors (as much as possible) in the design, development, construction and final implementation of the MICROPIK model. Obviously, such coordination requires a great deal of lead-time; and much to my chagrin, can not be modeled in a multiple-alternatives setting (or can it?).

Another obviously major portion of the intended piloting of the MICROPIK formulation will depend upon the ability of school districts to define their desired CAI/CMI needs; and then relate these needs to specifically definable and measureable instructional activities. States such as WASHINGTON which have begun concerted efforts to direct each school district to develop "student learning objectives" (SLOs) for each disciplinary or curriculum area, will provide greater facilitation in the final derivation of CAI and CMI curricular objectives and instructional activities. And of course, only those school districts which have the necessary microcomputer hardware and courseware will be included in the project if they so desire. Large purchases for data processing technology is not a priority item for districts who are currently forced to RIF classroom teachers due to budgeting problems.

The interested reader is invited to contact the author, and begin communications which might provide a basis for cooperative ventures in satisfying the uncoming requirements for a full-scale field research. Others are invited to stay tuned to further developments in the MICROPIK process, and its impact upon the general evaluation and decision-making structure currently found in most school districts ... same BYTE time ... same BYTE channel.

# PART III

# EXAMPLE OF A COMPLETE QUANTITATIVE SOLUTION

## CHAPTER 09

# THE UNDERSTANDING STAGE

[ Illustrating the Stepwise Implementation
of a Field-Based Quantitative Application ]

# THE FIELD APPLICATION

NOTE: Portions of this field pilot were conducted by John M. Sullivan of Sumner, Washington -- who was listed as second author to an earlier writing writing and documentation of this investigation.

Part III now prepares to address the issue of actually operationalizing the claims of the first and second parts. That is, can a structured decisioning system be formulated to evaluate the specific criterion-referenced alternatives of various program units for fiscal roll-back in a budgetary crisis; and can such a criterion-referenced, multiple-alternatives model be utilized confidently in a funding deallocation situation?

The author has had the distinct (though unfortunate) advantage of residing in a state which now finds itself in the midst of a severe, financial emergency. In all sectors of education, from the state policy level to the realm of the classroom teacher, alternatives are now being studied to brace for a cut to state-support for both K-12 and post-secondary education. To present the design and utility of the ROLBAK formalization, a single school district has been selected for the required piloting activities to demonstrate the ROLBAK formulization.

## Need for the Research

In an age of expanding technology, the role of sophisticated approaches to decision-making has become more accessible to the field administrator. Nothing supports this view more strongly than the recent advance of computer technology in particular. Yet, those individuals who could best afford the advantages of such sophistication remain the greatest obstacles to the acceptance of sophisticated tools as a beneficial tool for data analysis and evaluation. The situation surrounding the funding deallocation of specific programs is a clear example.

Scant resources require a revision of expanding service activities. Compounding the problem of forced decline is the fact, that many years of affluence in the availability of wide, diverse service delivery now clouds the issue of which services are essential and which are a luxury -- that is, the difference between entitlement on the one hand, and enrichment on the other. Therefore, the evaluation of current operating programs for possible elimination (or reduction) will not only require assessment of performance, but also a measure of the program's demand and need. As the decision-maker adds the criteria of need and demand to the already generic criterion list of effectiveness, efficiency, satisfaction and expenditure, the role of a multiple alternatives formulation to determine programs for retention vs. reduction via an analysis of multiple, competing criteria becomes paramount.

Finally, the need for a demonstration of a criterion-referenced, multiple-alternatives decisioning model is dictated by the parallel need of due-process. Not only does the decision maker need to be convinced of the efficacy of a carefully formulated MAM framework, but the program participants themselves need a firm understanding of the modeling perspective. People affected by the model-generated solutions (in this case, programs to be terminated) must accept that their personal interests were part of the decision, and that the relevant criteria were taken into account in the preparation of the final decision.

## Purpose of the Research

The mission of this undertaking is two-fold; first, to *demonstrate* the development and design of the multiple-alternatives analysis framework for the area of fiscal roll-backs; and second, to *assess* the relevant issues of decision validity and model reliability for the reader and potential user. We as scientists fully realize, that acceptance of our technique can reasonably come only after maximal critique and scrutiny. We have endeavored to step-by-step annotate the development of the ROLBAK mdoel for this particular study. And, we have employed the use of parametric statistical procedures in order to assess the model's impact upon the task at hand.

That task is this. Given an existing district program of 31 individual and distinct units, and the costs involved -- prepare, execute and evaluate the results of a mathematical modeling procedure which utilizes a criterion-referenced base for determining which program units remain operational, and which program units must be discontinued.

The criteria involved represent the identified expenditure requirements of each program unit, delineated across the eight "object" categories of a program budget; and a single meausre of subjective opinion on the part of central office administrators as to which units are more important than others. We limit the inclusion of criterion references to only nine indicators *for convenience only*. Many other measures must be included in the final determination of units to be deallocated. However, the demonstration of the model's utility will not require the loading of all relevant criteria into this piloting-formulated model.

## Overview of the Research

The outline for the contents of Part III have been constructed to accommodate a chronological discussion of the ROLBAK model's design, data construction, execution, and post-hoc evaluation.

The following section deals with the construction of the database for subsequent MAM-analysis. The next two sections will then present the rationale and methodology for utilizing the T-normal transformation of the new-scaled measures (dollars of expenditure). In addition, a brief discussion of special considerations in dealing with scant matrices will be presented.

The fifth section deals entirely with the search for initial model feasibility -- that is, the identification of the correct mix of constraint values (RHS) to permit an initial solution to the model.

The next two sections present the results (solutions) developed through the use of "restricted" and "relaxed" models, respectively. These two sections have been developed separately to highlight the differential impact of weighting.

The final two sections provide both a comparison of the restricted versus relaxed solutions, and a generalized discussion of the total ROLBAK performance under analysis.

## CONSTRUCTION OF THE DATABASE

Although an actual field application (i.e. "for real") of ROLBAK to a fiscal emergency would necessarily include many criterion references to effectiveness, efficiency, need, demand, satisfaction and expenditure; the authors have limited the pilot of ROLBAK to a small aggregate of measures. Under the broad title of 'database' will exist the numerical values required to operationalize the functions of the constraint matrix, conditional vector (RHS), and the objective function. Finally, three distinctly different scales will be used to demonstrate the versatility of the model's data-input requirements.

### Source of Data

Data for the model's execution represents two generalized measures: (1) a measure of expenditure requirement(s), in thousands of dollars; and (2) a measure of subjective bias, ordinally-scaled in units of rank (i.e., 1,2,3,...).

The expenditure data is input to the model in two separate fashions. The first, segregated by object-category, provide eight (8) separate expenditure amounts for each of the program units under consideration. These object categories are defined as projected allocations for:

1. CERT - certificated salaries
2. CLAS - classified salaries
3. BENE - employee benefits
4. SUPL - supplies and materials
5. INST - instructional supplies
6. CONT - contractual services

7. TRAV - travel expenditures
8. CAPI - capital outlay

These measures (originally in $1000's) will be later transformed into T-normal scores. Secondly, a category of 'total expenditures' required will be input to the model. This particular constraint will be utilized to efficiently control the 'cutting bias' of the model execution.

The second, general input manner will be an ordinal "rank of perceived expendability" attributed to each of the individual program units. Central office administrators were directed to rank the programs under consideration as to their degree of relative expendability, with 1 = most expendable.

For this particular ROLBAK pilot, a total of 31 programs were evaluated to determine the membership of the target set for deallocation. The criterion indicators to perform the MAM analysis included eight measures of object expenditure and a measure of perceived expendability, as well as a measure of composite expenditure.

## Method of Data Generation

Total projected expenditures for each of the 31 identified program units were delineated into 8 object categories, as available from district office budgeting records. The rank-measures of perceived expendability portray composites from the aggregated ranks of four staff members: superintendent, assistant superintendent, and two administrative assistants.

In addition, the eight objects were summed to provide a measure of projected total expenditure by unit. The utility of this composite measure will be discussed in a later section. Where no expenditures were noted for a particular program under a specific object, the value of 0 (zero) was assumed. Such zero-cells form a scant (or sparse) matrix. Necessary controls for the analysis of scant matrices are discussed in the succeeding two sections.

## Matrix Formating for MAM Utilization

<Figure 8> displays the raw database to be transformed to T-normals (see next section) and subsequently evaluated by the MAM procedure. Note that the model will incorporate 10 criterion measures for analysis: expenditure by object (8), total expenditure by unit (1), and perceived expandability (1). As will be discussed in a later section, the total unit expenditure criteria will be utilized twice under actual model execution: once to establish a level of minimal cuts, and the second to provide a upper bound on the model's 'cutting' (we did not want the procedure to go "wild").

Recall the reason for the database described in <Figure 8>. These measures will guide the ROLBAK analysis in determining which units will be allocated vs. deallocated funding -- based not only upon their expected expenditure by object but also upon their degree of perceived expendability. In addition, the measure of total unit expenditure (across all 8 objects) will be utilized to control for determining when "enough cuts" have been made to balance the new budget limitations.

Figure 8. Initial Raw Data Base for T-Normal Transformation and Entry into ROLBAK Procedure.

| PRG | Budgeted Expenditures in $1000 by Object | | | | | | | | TOTAL | PCP |
|---|---|---|---|---|---|---|---|---|---|---|
| | OBJ-1 [CERT] | OBJ-2 [CLAS] | OBJ-3 [BEDE] | OBJ-4 [SUPL] | OBJ-5 [INST] | OBJ-6 [CONT] | OBJ-7 [TRAV] | OBJ-8 [CAPI] | | |
| 01 | 55.0 | | | 5.5 | 20.0 | | | 7.0 | 87.5 | 19 |
| 02 | 19.0 | 5.0 | .5 | 3.5 | 3.0 | 1.0 | | 12.5 | 44.5 | 18 |
| 03 | 19.0 | 5.0 | .5 | | | | | 10.0 | 34.5 | 23 |
| 04 | 54.0 | | | 1.0 | 9.0 | .5 | .5 | 6.5 | 71.5 | 13 |
| 05 | 53.0 | | | 5.5 | 10.0 | 1.5 | | .5 | 70.5 | 14 |
| 06 | 20.0 | | | 1.0 | 7.5 | | | 4.0 | 32.5 | 15 |
| 07 | 40.0 | | | 3.0 | 5.0 | .5 | | 3.0 | 51.5 | 16 |
| 08 | | | | | | | | 1.5 | 1.5 | 25 |
| 09 | | 3.0 | | 19.0 | 3.5 | | | 17.5 | 43.0 | 4 |
| 10 | | | | | | 3.0 | | 1.0 | 4.0 | 17 |
| 11 | | 13.0 | 1.0 | 16.0 | | 16.0 | | 8.0 | 54.0 | 21 |
| 12 | | 1.0 | | | | | | | 1.0 | 2 |
| 13 | | | | | 5.0 | | .5 | | 5.5 | 24 |
| 14 | 3.0 | | | | | .5 | | .5 | 4.0 | 20 |
| 15 | | 39.0 | 3.5 | 3.5 | | 36.0 | | 34.0 | 116.0 | 11 |
| 16 | | | | | | 1.0 | | 22.0 | 23.0 | 7 |
| 17 | | | | | | | | 107.0 | 107.0 | 10 |
| 18 | | | | 13.0 | | | | | 13.0 | 1 |
| 19 | | 2.0 | | | | | | | 2.0 | 9 |
| 20 | | | | 1.0 | | | | | 1.0 | 8 |
| 21 | 14.0 | | 1.5 | | | | | .5 | 16.0 | 30 |
| 22 | | | | | | .5 | | 10.0 | 10.5 | 28 |
| 23 | | 34.0 | 9.5 | | 11.5 | | | | 55.0 | 26 |
| 24 | 1.0 | | .5 | | 2.0 | 1.0 | | | 4.5 | 29 |
| 25 | | | | | 2.0 | .5 | | | 2.5 | 31 |
| 26 | 10.0 | 3.0 | | | | | | 6.0 | 19.0 | 12 |
| 27 | | | | 1.0 | | | | | 1.0 | 3 |
| 28 | | | | 1.0 | | | | | 1.0 | 5 |
| 29 | 1.0 | .5 | .5 | | | | | | 2.0 | 22 |
| 30 | | | | 2.0 | | 10.0 | | | 12.0 | 27 |
| 31 | | | | | | 2.5 | | | 2.5 | 6 |

# INITIAL T-NORMAL TRANSFORMATIONS

One of the original directions to this text was to present the versatility of the MAM framework to accept a wide array of measurement scales as indicators for the values of the criteria. Although not discussed at length, all scales (i.e. nominal, ordinal, interval and ratio) can be accommodated by the MAM model.

In addition, the MAM framework in general and ROLBAK in particular, can be structured to model one of two situations (or both) concerning measured impact: impact of the system modeled specific to the individual effect for each alternative's value; and impact to the system modeled generalized to the collective effect for all alternatives' values. Briefly, the need for control of specific, individual effect (the former) addresses the need to measure the utility of each program alternative, and its absolute ability to coexist with other alternatives as part of the solution set. The use of a control for generalized, collective effect (the latter) however, addresses a less rigorous need to measure the utility of a program alternative, and its relative ability to become a member of the solution set.

Extensive research has been accomplished over the past five years by this author to understand the implications of a generalized, collective measurement system for criterion evaluation and control. Specifically, this research has centered about the usefulness of standardized (normalized) measures to accomplish this collective control need. Early work with z-scores was satisfactory, but required vigilance for the arithmetic impact of weights beneath the mean, that is, the negative values of z-score. Conversion to T-normals precluded such concern, and forms the primary measurement scale for the object expenditures in the ROLBAK model.

The use of standardized measures allows the decision-maker to measure the relative impact of each criterion's weight (for each unit alternative) without being concerned about the specific dollar amount. Reliance upon relative impact via the "object" criteria is valid within the ROLBAK system, since an additional criterion of total expenditure for each program unit is present.

## Transformation Considerations for a Scant Matrix

Before proceeding with a specific illustration of normalized transformation, we add a cautionary note concerning data matrices with a high number of empty cells, Empty cells normally mean one of two things: either the measure was 'zero', and therefore a zero was entered; or the criterion was inappropriate to that particular alternative, and therefore no measure is possible. As we said much earlier, the choice of relevant criteria which are applicable across all alternatives will preclude the model builder from the need to control for sophisticated confounded effects from irrelevant criterion variables.

For ROLBAK, the amount of zero-cells demonstrating zero-cost in particular objects for certain alternatives is very large -- large enough to call the data matrix a "scant" or "sparse" matrix (more zeros than not). To control for this situation, and to provide a better environment for the use of the RHS control values, we chose to exclude the empty cells from calculation of the normalized measures.

This is to say (please read very carefully now), that:

> the normalized values associated with a particular criterion, demonstrate the relative weight of that criterion for the individual unit, relative to the other

unit weights where such criterion expenditure actually exists.

(You can stop reading carefully now!)

In effect, the zero weights denoting no expenditure are not part of the original distribution that will compute the standardized measures; and thus the calculated weights will be more conversant with the other unit values where criterion expenditure actually exists.

## First Stage Transformation to Z-Scores

The following subsections are presented in brief to help those readers who have misplaced their statistics knowledge (who has not?).

A z-score is a normalized measure, standardized to reflect the relative weights of each of the 'raw data' values which form a specific distribution of scores (in our specific case, the distribution of expected expenditures, by object category). A z-score represents the mean of the raw distribution as a '0.00', and the standard deviation as a '±1.00'. That is, a raw score which represents a single standard deviation above the mean of the distribution is computed as a +1.00. If a score is one and one-half times the standard deviation below the mean, it is represented as -1.50; and so forth.

For the zealots among you, the transformation formula for computing a z-score form a raw distribution is a follows:

$z_i$

where,

$X$ (mean)

and,

$s$ (standard deviation)

subject to,

$i, = 1,2,\ldots,N$ values.

## Second Stage Transformation to T-Normals

The use of T-normals is simply suggested as a useful technique for circumventing the negative vlues of z-scores (or z-normals, if you wish). T-normals are standardized measures, with a mean of 50.00 and a standard deviation of 10.00. Thus, a negative T-normal would result only from a raw measure, whose value resides greater than 5 standard deviations below the mean of the distribution (somewhat unlikely, in the usual case).

T-normals are computed directly form z-scores, as follows:

$$T_i = 10.0(z_i) + 50.0,$$

such that a $z = -1.0$ becomes a $T = 40.0$, a $z = +2.5$ becomes a $T = 75.0$, and so forth.

# FORMULATION OF THE ROLBAK MATHEMATICAL MODEL

The reader is redirected to <Figure 7> to review the format of the generalized MAM framework. Recall that the model utilizes three distinct though obviously interrelated segments. The first, the constraint matrix, contains the coefficients for the system of simultaneous linear inequalities (and equalities), whose independent variables are the alternative program units. Therefore, these coefficient values are really the criterion measures associated with each independent variable's "performance" or "need".

The second distinct segment, the conditional vector (or "right-hand-side"), contains the composite measures which restrict the summations of the coefficients of the independent variables, as those independent variables are evaluated for inclusion within the final solution set. These RHS-values are the upper (or lower) bounds associated with the linear inequalities, and the exact standard associated with any linear equation.

The last segment, the objective function, provides the guiding force behind the selection of alternatives for membership within the solution set. Remember that objective function (sometimes referred to as cost vectors, whether measuring cost or not) must be either maximized or minimized, depending upon the objective of the problem modeled. Maximizing (or minimizing) the summation of the objective function is referred to as (in fashionable circles, of course) as optimization.

Under optimality then, the goal of the model is as follows:

> to formulate the "best" solution mix of alternatives based upon the values of the objective function; given

the constraints defined by the simultaneous system of inequalities (and equalities) as modeled by the constraint matrix, and the limits provided by the conditional vector.

## The Constraint Matrix

To formulate the ROLBAK problem, a total of 31 individually funded programs were defined for evaluation. Each program's budget was delineated into it's individual 'object expenditure' requirements (certificated salaries, instructional supplies, etc.). These initial eight expenditure breakdowns form the first 8 constraints of the constraint matrix; and are entered as T-normal transformations. The next two constraints are identical vectors containing the total, composite expenditure requirements for each program unit. Expressed in thousands of dollars, these two vectors will provide the basis for controlling the model's final, total amount of final deallocation. The last constraint vector, in the matrix, contains the ranked values for the "perceived expendability" of each unit; where 1 = most expendable and 31 = least expendable.

Thus the criterion coefficients of the constraint matrix represent three distinct measurement features: T-normals measured in standard units, total expenditure measured in thousands of dollars, and expendability measured in ordinal ranks.

## Conditional Vector for a Scant Matrix

The RHS-values of the conditional vector served to operationalize the simultaneous system of the constraint matrix; that is, they establish the limits which the vector-coefficients summations must comply with.

For the initial 8 object-expenditure constraints, the RHS-values are computed to effect a generalized impact upon the system as a whole treating all objects equally. Thus, expenditures projected in any one category do not place their associated programs in weighted jeopardy. Although in some modeling cases such weighting will be desireable, the current example weights all equally for demonstration purposes. These specific values will be discussed at length in the next section.

The next two constraint vectors are identical in that their coefficients represent composite object expenditures for each program. The district's current operating budget comprised 893.5 (thousands) dollars. The goal of the model was to develop a plan for effecting a revised operating level of not less than 675.0 dollars (1000's) nor greater than 700.0 dollars (1000's). To model this objective (constraint), the sum of the first vector was limited to 675.0 (greater than or equal, and the sum of the second vector to 700.0 (less than or equal). In effect, this "bracketing" allows a 25.0 dollars (1000's) flexibility factor for model evaluation.

The final constraint, the measure of perceived expendability, was modeled to effect a smaller sum (minimized). This was necessitated due to the fact that a smaller rank represented greater expendability -- and thus, the sum of smaller values produces a "preferred" smaller amount.

The considerations required for a scant matrix involve only the first 8 inequality vectors. However, the sum of zeros will not deter from the utility of the conditional vector in successfully controlling the sum of the remaining sums. Since the empty cells represent no expenditure for that particular object, the choice of the associated program unit will not contribute to the RHS-requirement (limit). (Again, please refer to the next section for a more detailed discussion.)

## Cyclical Objective Function

Since the construction of the objective function, and the subsequent maximization or minimization of its sum, defines what we call 'optimality', the content to the O.F. is a biasing factor to the model's evaluation of alternatives. It is reasonable to expect a different mix of solution alternatives, if the model utilizes a different objective function or changes from maximization to minimization of the same objective vector.

ROLBAK examines the effect such manipulation has upon solution results by cycling each individual constraint vector through a separate execution as the objective function. Moreover, the focus is altered to investigate both optimality directions, maximization and minimization.

## The Problem

Given the structure of the MAM framework discussed above, the resulting ROLBAK model will select ($X_j = 1$) those program units to be retained, that are to receive funding.

## SEARCH FOR REGIONAL FEASIBLITY AS BENCHMARK

The initial attempts in executing a MAM-designed solution, requires the establishment of *first*, initial region feasiblity of the decision space, and *second*, a benchmark from which the manipulation of RHS-weighting and cyclical optimization can both be measured. Decision space (regional) feasibility simply means that at least one solution exists which satisfies the requirements of the constraint matrix and conditional vector. If no solution exists, under any circumstance allowed by the linear inequalities and equalities, then the decisioning (constraint) region is declared to be "infeasible"; and the model either altered or abandoned.

Once feasibility is determined, a benchmark is established to begin the cyclical evaluation of the various agreed-upon criterion values. The benchmark may in fact be the initial point at which feasibility is determined. However, *serious* practitioners of the art (obviously us!) will search for two separate modeling configurations from which to observe the effect of the varying optimality criteria. These separate configurations can best be addressed as states of *restriction* and *relaxation*.

The restricted model contains RHS-values which force the execution to choose its solution set most carefully; that is, the limits imposed are very restrictive as to what is allowable to constitute a solution. On the other hand, the relaxed model utilizes such RHS-values as will invite solution set membership patterns which widely differ. The authors have chosen both so as to please even the most skeptical of our readers.

## 'N' of the Scant Matrix

The normal procedure in attempting to establish feasibility is to arbitrarily project the number (N) of solution which is likely to result from the successful implementation of the model. With the use of T-normals, and the given T(mean) = 50.0 and T(standard deviation) = 10.0, the arbitrary N can be used to establish a beginning RHS-value:

$$N(50.0 + 10.0) = N(60.0)$$

for a perceived upper bound; and:

$$N(50.0 - 10.0) = N(40.0)$$

for a perceived lower bound. (The rationale for such considerations has been discussed at length in a previous chapter of this report.)

The existence of a scant matrix however provides a rather unique situation concerning such 'N' formulation. That is, the N's concerning each criterion across all alternatives will differ, based upon the number of empty (i.e. zero) cells. And in fact for this particular ROLBAK formulation, this is exactly the case. Referring to Figure 8 (on page ), you will see that the number of non-zero cells are as follows:

CERT = 12
CLAS = 10
BENE = 8
SUPL = 14
INST = 10
CONT = 14
TRAV = 2
CAPI = 18.

Under these circumstances, the useful relationship of

$$N(T(Mn) + T(S.D.))$$

must be changed to

$$N_k(T(Mn) + T\ (S.D.))$$

for *each* separate k = 1,2,...,8 of the object expenditure categories.

## Expected Solution Index

The expected solution index (ESI) controls for *both* the existence of a scant matrix of zero-cells, and the necessity to investigate varying levels of solution N's -- that is, the number of units which may be members of the final solution set. Although inextricably related, we will develop each separately for the sake of understanding their unique contribution.

The existence of a scant matrix will provide a varying number of non-zero cells. To operationalize the utility of the N(T(Mn) + T(S.D.)) idea, we must vary the N for each computation of the particular RHS-value. Furthermore, the region of feasible solution(s) will likewise require the search for a suitable (expected) solution set size; that is, to allocate (for example) funds to 10 programs; or 12; or 14; etc.

The EIS is calculated to take into account *both* scant matrices and varying solution set membership by utilizing the postulate:

$$\frac{(N > 0)(E)}{N(\text{total})}$$

where,

$(N > 0)$ = number of non-zero cells for the given criterion constraint;

$(E)$ = number of expected solution set alternatives; and

$N(\text{total})$ = number of total possible alternatives.

In our ROLBAK example, this expression can be reduced to

$$\frac{(N > 0)\ (E)}{31} .$$

For example, if we were to examine the ESI for the "certificated salaries" constraint (12 non-zero cells) and an expected solution membership of 10, the index based upon the $(N > 0)$ would be calculated as:

$$\frac{N>0}{31} = \frac{12}{31} = .387 \ ,$$

and with the expected membership (E) of 10,

$$\frac{N>0}{31}\ (E) = .387(E) = .387(10) = 3.87$$

This index and its relationship to the T-normal values will be described in the next subsection.

## RHS-Values by Index

<Figure 9> summarizes the calculation of RHS-values utilizing the idea of an expected solution index (ESI) for a scant matrix. for example, given the constraint of certificated salaries (CERT), with 12 non-zero entries and an expected solution membership of 10 units, the RHS-value would be computed as:

$$\frac{12(10)}{31} (50.0 - 10.0) = 3.87 (40.0) = 155.0,$$

assuming that a "linear bound" is the desired RHS intention.

The RHS-values for PERC and COMP are arrived at arbitrarily as well, but without resorting to the above scheme for T-normals.

## Search for Feasibility

Use of the ESI system discussed in the preceding subsection established immediate feasibility, with concurrent values for PERC and COMP as shown. Any value for PERC less than 500, however, lost the feasible region.

## Search for Benchmark

The range of expected membership values was varied from E = 10 to E = 16, and the definition(s) of relaxed benchmark attached to:

E = 16; PERC = 500,

and restricted benchmark attached to:

E = 10; PERC = 600.

Figure 9. Computation of Conditional Vector (RHS) Values for Constraint Matrix with Zero Sub-Matrices and Cell-Entries Based Upon T-Normal Scores

| | | | | RHS-Values by Expected Index** | | | |
|---|---|---|---|---|---|---|---|
| Criterion Constraint | Code | N>0 | INDEX* | E=10 | E=12 | E=14 | E=16 |
| Certificated Salaries | CERT | 12 | .389 | 155 | 186 | 217 | 248 |
| Classified Salaries | CLAS | 10 | .323 | 129 | 155 | 181 | 206 |
| Employee Benefits | BENE | 08 | .258 | 103 | 124 | 145 | 165 |
| Supplies & Materials | SUPL | 14 | .452 | 181 | 217 | 253 | 289 |
| Instructional Supplies | INST | 10 | .323 | 129 | 155 | 181 | 206 |
| Contractural Services | CONT | 14 | .452 | 181 | 217 | 253 | 289 |
| Travel Expenditures | TRAV | 02 | .065 | 026 | 031 | 036 | 041 |
| Capital Outlay | CAPI | 18 | .581 | 232 | 279 | 325 | 372 |
| Administrative Perception | PERC | 31 | (Restricted = 500 / Relaxed = 600) | | | | |
| Composite Budget | COMP | 31 | (Lower Limit = 675.0 / Upper Limit = 700.0) | | | | |

* Index = $\frac{N>0}{31}$

** RHS (EXP) = [N>0] [T(Mn)± T(SD)] / 31 = (Index) (Tm±10), where:
1. Index (40) for Lower Bound (≥)
2. Index (60) for Upper Bound (≤)

Since the object categories were constrained to force summations greater than or equal to the RHS-values established by the ESI, the larger the RHS-value, the more difficult to find an acceptable solution -- therefore, the more restricted. Likewise, for the relaxed system and smaller values of the RHS.

For the purposes of the remainder of this chapter, the restricted and relaxed benchmarks will be utilized to observe the effects of cyclical optimization upon solution set membership.

# CYCLIC OPTIMIZATION OF THE RESTRICTED MODEL

The first of two major quantitative assessments, the cyclic optimization of each of ten (10) criterion linear (convex) combinations as the objective function, produced analyzable results under both maximization and minimization. This section will study these results, and address their relationship to both the model's execution and the criteria utilized, for the restricted model.

## Maximized/Restricted Solutions

‹Figure 1› displays the results of the various cyclical maximizations within the restricted setting. Of the possible combinations of the available 31 units for solution membership, only two distinct solution sets were formed. The mix set of 10 entries

[ 01,02,03,04,05,07,09,11,15,17 ]

produced a new budget of 680.0 dollars (1000's) for a savings of 213.5 dollars (1000's), in five cases. Similarly, anothe five instances formed the mix set of 10 entries

[ 01,02,04,05,07,11,15,16,17,23 ]

producing a new budget of 680.5 dollars for a savings of 213.0 dollars.

Additional technical data has been included within the figure for the more technically knowledgeable.

Figure 10. Effect Upon Budget Deallocation Decisions Based Upon the Variable Flows of a Cyclic Objective Function, and the Interaction of a "Maximized, Restricted" Constraint Iterative Problem.

Objective = Maximization    Constraints: Restricted (EXP=15; PERC = 500)

| Budget Alterna-tives | 01 CERT | 02 CLAS | 03 BENE | 04 SUPL | 05 INST | 06 CONT | 07 TRAV | 08 CAPI | 09 PERC | 10 COMP | SELECTION TALLY | BUDGET AMOUNT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | X | X | X | X | X | X | X | X | X | X | 10 | 87.5 |
| 02 | X | X | X | X | X | X | X | X | X | X | 10 | 44.5 |
| 03 | X | X |  | X |  |  | X | X |  |  | 5 | 34.5 |
| 04 | X | X | X | X | X | X | X | X | X | X | 10 | 71.5 |
| 05 | X | X | X | X | X | X | X | X | X | X | 10 | 70.5 |
| 06 |  |  |  |  |  |  |  |  |  |  | -- | 32.5 |
| 07 | X | X | X | X | X | X | X | X | X | X | 10 | 51.5 |
| 08 |  |  |  |  |  |  |  |  |  |  | -- | 1.5 |
| 09 | X | X |  | X |  |  | X | X |  |  | 5 | 43.0 |
| 10 |  |  |  |  |  |  |  |  |  |  | -- | 4.0 |
| 11 | X | X | X | X | X | X | X | X | X | X | 10 | 54.0 |
| 12 |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| 13 |  |  |  |  |  |  |  |  |  |  | -- | 5.5 |
| 14 |  |  |  |  |  |  |  |  |  |  | -- | 4.0 |
| 15 | X | X | X | X | X | X | X | X | X | X | 10 | 116.0 |
| 16 |  |  | X |  | X | X |  |  | X | X | 5 | 23.0 |
| 17 | X | X | X | X | X | X | X | X | X | X | 10 | 107.0 |
| 18 |  |  |  |  |  |  |  |  |  |  | -- | 13.0 |
| 19 |  |  |  |  |  |  |  |  |  |  | -- | 2.0 |
| 20 |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| 21 |  |  |  |  |  |  |  |  |  |  | -- | 16.0 |
| 22 |  |  |  |  |  |  |  |  |  |  | -- | 10.5 |
| 23 |  |  | X |  | X | X |  |  | X | X | 5 | 55.0 |
| 24 |  |  |  |  |  |  |  |  |  |  | -- | 4.5 |
| 25 |  |  |  |  |  |  |  |  |  |  | -- | 2.5 |
| 26 |  |  |  |  |  |  |  |  |  |  | -- | 19.0 |
| 27 |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| 28 |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| 29 |  |  |  |  |  |  |  |  |  |  | -- | 2.0 |
| 30 |  |  |  |  |  |  |  |  |  |  | -- | 12.0 |
| 31 |  |  |  |  |  |  |  |  |  |  | -- | 2.5 |
|  | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |  |  |
| O.F. Value: | 140.7 | 274.5 | 217.9 | 433.9 | 330.0 | 362.1 | 50.0 | 534.6 | 496.2 | 680.5 |  |  |
| Iteration at Optimality: | 26 | 69 | 76 | 115 | 228 | 27 | 114 | 51 | 5000+ | 369 |  |  |
| Time (secs): | .256 | .298 | .289 | .325 | .384 | .264 | .383 | .274 | 4.498 | .350 |  |  |
| Roll-Back Savings: | 680.0 | 680.0 | 680.5 | 680.0 | 680.5 | 680.5 | 680.0 | 680.0 | 680.5 | 680.5 |  |  |
| (- Cut) | (-213.5) | (-213.5) | (-213.0) | (-213.5) | (-213.0) | (-213.0) | (-213.5) | (-213.5) | (-213.0) | (-213.0) |  |  |

Note: Total Initial Budget = 893.5 ($1000's)

## Minimized/Restricted Solutions

Minimizing the various objective functions within the restrictive setting produced similar results as displayed in <Figure 11>. Four occurrences of the solution vector

[ 01,02,03,04,05,07,09,11,15,17 ]

and three occurrences of the solution vector

[ 01,02,04,05,07,11,15,16,17,23 ]

resulted in the minimized, restricted setting. Unlike maximized optimality however, the use of minimized objective functions failed to produce a solution in three separate instances.

## Validity Evaluation of the Restricted Model

Analysis of variance procedures were utilized to detect the extent of criterion difference between membership in the solution vs. non-solution sets. Since optimality within the restricted setting produced only two different combinations of solutions, these post hoc assessments were easy to execute. Results are presented in <Figure 12>.

A review of the ANOVA results show that in all cases except one, the mean values of the "included" criterion indicators were greater than the non-solutional weights; and were therefore consistent with model expectations and formulated constraints. The one exception occurs in both optimality settings when the perception of expendability was used as the O.F.

It is also interesting to note, that the

Figure 11. Effect Upon Budget Deallocation Decisions Based Upon the Variable Forms of a Cyclic Objective Function, and the Interaction of a "Minimized, Restricted" Constraint Interactive Problem.

Objective = Minimization     Constraints = Restricted (8xP=16; PERC=500)

| Budget Alterna-tives | 01 CERT | 02 CLAS | 03 BENE | 04 SUPL | 05 INST | 06 CONT | 07 TRAV | 08 CAPI | 09 PERC | 10 COMP | SELECTION TALLY | BUDGET AMOUNT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | | X | X | X | X | X | | X | X | | 7 | 37.5 |
| 02 | | X | X | X | X | X | | X | X | | 7 | 44.5 |
| 03 | | | X | | X | X | | | X | | 4 | 34.5 |
| 04 | | X | X | X | X | X | | X | X | | 7 | 71.5 |
| 05 | | X | X | X | X | X | | X | X | | 7 | 70.5 |
| 06 | | | | | | | | | | | -- | 32.5 |
| 07 | | X | X | X | X | X | | X | X | | 7 | 51.5 |
| 08 | | | | | | | | | | | -- | 1.5 |
| 09 | | | X | | X | X | | X | X | | 4 | 43.0 |
| 10 | | | | | | | | | | | -- | 8.0 |
| 11 | | X | X | X | X | X | | X | X | | 7 | 54.0 |
| 12 | | | | | | | | | | | -- | 1.0 |
| 13 | | | | | | | | | | | -- | 5.5 |
| 14 | | | | | | | | | | | -- | 3.0 |
| 15 | | X | X | X | X | X | | X | X | | 7 | 116.0 |
| 16 | | X | | X | | | | X | | | 3 | 23.0 |
| 17 | | X | X | X | X | X | | X | X | | 7 | 107.0 |
| 18 | | | | | | | | | | | -- | 13.0 |
| 19 | | | | | | | | | | | -- | 2.0 |
| 20 | | | | | | | | | | | -- | 1.0 |
| 21 | | | | | | | | | | | -- | 16.0 |
| 22 | | | | | | | | | | | -- | 10.5 |
| 23 | | X | | X | | | | X | | | 3 | 55.0 |
| 24 | | | | | | | | | | | -- | 4.5 |
| 25 | | | | | | | | | | | -- | 2.5 |
| 26 | | | | | | | | | | | -- | 19.0 |
| 27 | | | | | | | | | | | -- | 1.0 |
| 28 | | | | | | | | | | | -- | 1.0 |
| 29 | | | | | | | | | | | -- | 2.0 |
| 30 | | | | | | | | | | | -- | 12.0 |
| 31 | | | | | | | | | | | -- | 2.5 |
| | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | |
| O.F. Value: | -- | 234.5 | 197.0 | 356.8 | 314.8 | 313.0 | -- | 482.6 | 489.0 | -- | | |
| Iteration at Optimality: | -- | 5000+ | 686 | 200 | 85 | 902 | -- | 203 | 53 | -- | | |
| Time (sec): | -- | 4.531 | .333 | .563 | .304 | 1.193 | -- | .407 | .256 | -- | | |
| Pull-Back Savings: | -- | 680.5 | 680.0 | 680.5 | 680.0 | 680.0 | -- | 680.5 | 680.0 | -- | | |
| (-Cut) | -- | (-213.0) | (-213.5) | (-213.0) | (-213.5) | (-213.5) | -- | (-213.0) | (-213.5) | -- | | |

Note: Total Initial Budget = 893.5 ($1000's)

Figure 12. Summary of Cyclic Optimality Directions (of Criterion Objective Functions) Utilized in Guiding the Fully Restricted (EXP=16; PERC=500) Problem to Two Distinct Solutions; and Resulting Object Expenditure Impact.

Fully Restricted (EXP=16; PERC=500)

| Solution = (1,2,3,4,5,7,9,11,15,17) | | | Solution = (1,2,3,5,7,11,15,16,17,23) | |
|---|---|---|---|---|
| MAX | P= .02<br>I=34.1<br>X=12.4 | Certificated Salaried | P= .15<br>I=29.1<br>X=14.8 | --- |
| MAX | P= .07<br>I=27.4<br>X=10.7 | Classified Salaries | P= .25<br>I=23.4<br>X=12.6 | MIN |
| MIN | P= .27<br>I=19.7<br>X= 9.3 | Employee Benefits | P= .14<br>I=21.8<br>X= 8.3 | MAX |
| MAX | P= .00<br>I=43.4<br>X=12.9 | Supplies & Materials | P= .04<br>I=36.7<br>X=16.1 | MIN |
| MIN | P= .03<br>I=31.5<br>X=11.2 | Instructional Supplies | P= .02<br>I=33.0<br>X=10.6 | MAX |
| MIN | P= .21<br>I=31.3<br>X=13.6 | Contractural Services | P= .05<br>I=36.2<br>X=16.3 | MAX |
| MAX | P= .59<br>I= 5.0<br>X= 2.1 | Travel Expenditures | P= .59<br>I= 5.0<br>X= 2.4 | --- |
| MAX | P= .00<br>I=53.5<br>X=17.5 | Capital Outlay | P= .00<br>I=48.3<br>X=20.0 | MIN |
| MIN | P= .57<br>I=48.9<br>X=50.5 | Administrative Perception | P= .38<br>I=49.6<br>X=50.2 | MAX |
| --- | P= .00<br>I=68.0<br>X=10.2 | Budgetary Composites | P= .00<br>I=68.1<br>X=10.1 | MAX |

Cell Entries:

(P=) ... Statistical significance of mean difference, include v. exclude.
(I=) ... Mean budget amount for included object of budget revision.
(X=) ... Mean budget amount for excluded object of budget revision.

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[ 01,02,03,04,05,07,09,11,15,17 ]

pattern resulted in six (6) statistically significant differences while the other pattern resulted in only five (5). Though barely different in number, the criterion producing such differences (as O.F.) varied in both cases. The reader should recall that significant differences in criterion mean weights portray the ability of the model to utilize such criterion constraints within the decisioning and solution set building process.

## Reliability Evaluation of the Restricted Model

Discriminant function analysis was employed to study the consistency and predictability of the model's function in producing reliable solution sets.

<Figure 13> displays the discriminant results for solution set

[ 01,02,03,04,05,07,09,11,15,17 ].

The major criterion values predictive of the established solution is shown in the order of their importance. Re-prediction was established with 96.77 percent accuracy.

The results for the solution set

[ 01,02,04,05,07,11,15,16,17,23 ]

are found in <Figure 14>. In this case, only three criterion distributions were required to re-predict membership at an equivalent 96.77 percent accuracy.

Figure 13. Use of Discriminant Analysis in Predicting Program Inclusion for Budgetary Revision, Solution #1, Based Upon the Cyclic Optimization of the Restricted Problem.

| Budget | Incl | Budget | Incl | Budget | Incl | Budget | Incl |
|---|---|---|---|---|---|---|---|
| 01 | 1 | 09 | 1 | 19 | 1 | 25 | -- |
| 02 | 1 | 10 | -- | 18 | -- | 26 | -- |
| 03 | 1 | 11 | 1 | 19 | -- | 27 | -- |
| 04 | 1 | 12 | -- | 20 | -- | 28 | -- |
| 05 | 1 | 13 | -- | 21 | -- | 29 | -- |
| 06 | -- | 14 | -- | 22 | -- | 30 | -- |
| 07 | 1 | 15 | 1 | 23 | -- | 31 | -- |
| 08 | -- | 16 | -- | 24 | -- | | |

Summary of Criterion Value in Discriminating Inclusion Decisions:

| Step | Entered | Removed | Not Used |
|---|---|---|---|
| 1 | Budgetary Composites | | Employee Benefits |
| 2 | Supplies & Materials | | Instructional Supplies |
| 3 | Capital Outlay | | Contractural Services |
| 4 | Certificated Salaries | | Travel Expenditures |
| 5 | Classified Salaries | | Administrative Perception |

Classification Results From Predictive Validation:

(Percents in Parenthesis)

| Actual Group | (N) | Predicted Group Membership | |
|---|---|---|---|
| | | 0 | 1 |
| 0 | 21 | 20(95.2) | 1(4.8) |
| 1 | 10 | --- | 10(100.0) |

Percent of Grouped Cases Correctly Classified: 96.77

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Figure 14. Use of Discriminant Analysis in Predicting Program Inclusion for Budgetary Revision, Solution #2, Based Upon the Cyclic Optimization of the Restricted Problem.

| BUDGET | INCL | BUDGET | INCL | BUDGET | INCL | BUDGET | INCL |
|---|---|---|---|---|---|---|---|
| 01 | 1 | 09 | -- | 17 | 1 | 25 | -- |
| 02 | 1 | 10 | -- | 18 | -- | 26 | -- |
| 03 | -- | 11 | 1 | 19 | -- | 27 | -- |
| 04 | 1 | 12 | -- | 20 | -- | 28 | -- |
| 05 | 1 | 13 | -- | 21 | -- | 29 | -- |
| 06 | -- | 14 | -- | 22 | -- | 30 | -- |
| 07 | 1 | 15 | 1 | 23 | 1 | 31 | -- |
| 08 | -- | 16 | 1 | 24 | -- | | |

Summary of Criterion Value in Discriminating Inclusion Decisions:

| STEP | ENTERED | REMOVED | NOT USED |
|---|---|---|---|
| 1 | Budgetary Composites | | Certificated Salaries |
| 2 | Contractual Services | | Classified Salaries |
| 3 | Instructional Supplies | | Employee Benefits |
| | | | Supplies and Materials |
| | | | Travel Expenditures |
| | | | Capital Outlay |
| | | | Administrative-Perception |

Classification Results from Predictive Validation:

(Percent in Parenthesis)

| Actual Group | (N) | Predictive Group Membership 0 | Predictive Group Membership 1 |
|---|---|---|---|
| 0 | 21 | 21(100.00) | -- |
| 1 | 10 | 1 (10.0) | 9 (90.0) |

Percent of Grouped Cases Correctly Classified: 96.77

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## CYCLIC OPTIMIZATION OF THE RELAXED MODEL

The second of the two major quantitative assessments, the relaxed setting produced a wide diversity of solution sets. In fact, out of twenty executions and seventeen successful feasibilities, all seventeen solution sets were unique.

### Maximized/Relaxed Solutions

<Figure 15> displays ten unique solutions, one for each of the cyclic optimizations under maximization. All solutions were successful in rebudgeting between the 675.0 and 700.0 limits. It is perhaps more interesting to study the column of numbers labelled 'selection tally', on the right side of the figure. The repetition with which particular units were chosen for continued funding resembles closely the two solution sets constructed with the restricted model formulation.

### Minimized/Relaxed Solutions

Minimizing in the relaxed setting produced three failures at set building. Of the seven solution sets constructed, all are distinct; and different from the maximization sequence. <Figure 16> presents these data results.

The alert reader will also note that the relaxed setting produces varying numbers of units within the solution set (low of 10 to a high of 13 units selected).

Figure 15. Effect Upon Budget Deallocation Decisions Based Upon the Variable Flows of a Cyclic Objective Function, and the Interaction of a "Maximized, Relaxed" Constraint Iterative Problem.

Objective - Maximization    Constraints: Relaxed (EXP-10; PERC - 600)

| Budget Alterna-tives | 01 PERS | 02 CLAS | 03 BENE | 04 SUPL | 05 INST | 06 CONT | 07 TRAV | 08 CAPI | 09 PERC | 10 COMP | SELECTION TALLY | BUDGET AMOUNT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | X | X | X | X | X | X | X | X | X | X | 10 | 87.5 |
| 02 | X | X | X | X | X | X |  | X |  |  | 7 | 44.5 |
| 03 | X | X | X |  |  |  | X | X |  |  | 5 | 34.5 |
| 04 | X | X | X | X | X | X | X | X | X | X | 10 | 71.5 |
| 05 | X |  | X | X | X | X | X |  | X | X | 8 | 70.5 |
| 06 | X |  |  | X | X |  | X | X | X |  | 6 | 32.5 |
| 07 | X | X |  | X | X | X | X | X | X | X | 9 | 51.5 |
| 08 |  |  |  |  |  |  |  |  |  |  | -- | 1.5 |
| 09 | X | X | X | X | X | X | X | X | X | X | 10 | 43.0 |
| 10 |  |  |  |  |  | X |  |  |  |  | 1 | 4.0 |
| 11 |  | X | X | X |  | X |  | X |  | X | 6 | 54.0 |
| 12 |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| 13 |  |  |  |  | X |  | X |  |  |  | 2 | 5.5 |
| 14 |  |  |  |  |  |  |  |  | X |  | 1 | 4.0 |
| 15 | X | X | X | X | X | X | X | X | X | X | 10 | 116.0 |
| 16 |  |  |  |  |  | X |  | X | X | X | 4 | 23.0 |
| 17 | X | X | X | X | X | X | X | X | X | X | 10 | 107.0 |
| 18 |  |  |  | X |  |  |  |  | X |  | 2 | 13.0 |
| 19 |  | X |  |  |  |  |  |  |  |  | 1 | 2.0 |
| 20 |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| 21 | X |  | X |  |  |  |  |  |  |  | 2 | 16.0 |
| 22 |  |  |  |  |  |  |  | X |  |  | 1 | 10.5 |
| 23 |  | X | X |  | X |  | X |  | X | X | 6 | 55.0 |
| 24 |  |  |  |  |  |  |  |  |  |  | -- | 4.5 |
| 25 |  |  |  |  |  |  |  |  |  |  | -- | 2.5 |
| 26 | X | X |  |  |  |  | X |  |  | X | 4 | 19.0 |
| 27 |  |  |  | X |  |  |  |  |  |  | 1 | 1.0 |
| 28 |  |  |  | X |  |  |  |  | X |  | 2 | 1.0 |
| 29 |  |  |  |  |  |  |  |  |  | X | 1 | 2.0 |
| 30 |  |  |  |  |  | X |  |  |  |  | 1 | 12.0 |
| 31 |  |  |  |  |  |  |  |  |  |  | -- | 2.5 |
|  | 12 | 12 | 11 | 13 | 11 | 12 | 12 | 12 | 13 | 12 |  |  |
| O.F. Value | 3[illegible]5.4 | 425.5 | 316.1 | 615.9 | 476.6 | 477.7 | 100.0 | 659.04 | 600.0 | 700.0 |  |  |
| Iterating at Optimality: | 20 | 60 | 202 | 16 | 43 | 52 | 163 | 65 | 5000+ | 457 |  |  |
| Time (Secs.) | .216 | .359 | .416 | .227 | .297 | .337 | .569 | .310 | 6.022 | 1.166 |  |  |
| Roll-Back Savings: | 685.5 | 685.5 | 699.5 | 693.0 | 684.5 | 684.5 | 693.5 | 675.5 | 675.5 | 700.0 |  |  |
|  | (-[illegible].0) | (-208.0) | (-194.0) | (-200.5) | (-209.0) | (-209.0) | (-200.0) | (-218.0) | (-218.0) | (-193.5) |  |  |

Note: Total Initial Budget - 893.5 ($1000's)

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Figure 10. Effect Upon Budget Deallocation Decisions Based Upon the Variable Flows of a Cyclic Objective. Function, and the Interaction of a "Minimized, Relaxed" Constraint Iterative Problem.

Objective - Minimization Constraints: Relaxed (CAP-10; PERC - COM)

| [illegible] | [illegible] | [illegible] | 03 [illegible] | 04 SUPP | 05 INST | 06 CONT | 07 TRAV | 08 CAPI | 09 PERC | 10 COMP | SELECTION TALLY | BUDGET AMOUNT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [illegible] | x |  | X | X | X | X | X |  | X |  | 7 | 87.5 |
| [illegible] | x |  |  | X | X | X |  |  | X |  | 5 | 44.5 |
| [illegible] |  |  |  | X | X | X |  |  |  |  | 3 | 34.5 |
| [illegible] | x |  | X | X | X | X | X |  | X |  | 7 | 71.5 |
| [illegible] |  |  | X | X | X |  | X |  | X |  | 5 | 76.5 |
| [illegible] |  |  | X |  |  | X | X |  | X |  | 4 | 32.5 |
| [illegible] | x |  | X | X |  | X | X |  | X |  | 6 | 51.5 |
| [illegible] |  |  |  |  |  |  |  |  |  |  | -- | 1.5 |
| [illegible] | x |  | X |  | X | X | X |  | X |  | 5 | 43.0 |
| [illegible] |  |  |  |  |  |  |  |  |  |  | -- | 4.0 |
| [illegible] | x |  | X |  | X |  | X |  | X |  | 5 | 54.0 |
| [illegible] |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| [illegible] |  |  | X |  |  |  |  |  |  |  | 1 | 5.5 |
| [illegible] |  |  |  |  |  |  |  |  |  |  | -- | 4.0 |
| [illegible] | x |  | X | X | X | X | X |  | X |  | 7 | 116.0 |
| [illegible] | X |  | X | X | X |  | X |  |  |  | 5 | 23.0 |
| [illegible] | x |  | X | X | X | X | X |  | X |  | 7 | 107.0 |
| [illegible] | x |  | X |  | X | X |  |  |  |  | 4 | 13.0 |
| [illegible] |  |  |  |  |  |  |  |  |  |  | -- | 2.0 |
| [illegible] |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| [illegible] |  |  |  |  |  |  | X |  |  |  | 1 | 16.0 |
| [illegible] | x |  |  |  |  |  |  |  |  |  | 1 | 10.5 |
| [illegible] | x |  |  | X |  | X |  |  |  |  | 3 | 55.0 |
| [illegible] |  |  |  |  |  |  |  |  |  |  | -- | 4.5 |
| [illegible] |  |  |  |  |  |  |  |  |  |  | -- | 2.5 |
| [illegible] |  |  |  | X | X | X | X |  |  |  | 4 | 19.0 |
| [illegible] |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| [illegible] |  |  | X |  |  |  |  |  |  |  | 1 | 1.0 |
| [illegible] |  |  |  |  |  |  |  |  |  |  | -- | 2.0 |
| [illegible] |  |  |  |  |  |  |  |  |  |  | -- | 12.0 |
| 31 |  |  |  | X | X |  |  |  |  |  | 2 | 2.5 |
|  | [illegible] | -- | 13 | 12 | 13 | 12 | 12 | -- | 10 | -- |  |  |
| [illegible] | [illegible] | -- | 110.0 | 304.7 | 265.9 | 198.3 | 50.0 | -- | 482.3 | -- |  |  |
| Iteration at [illegible] | [illegible] | -- | 5000+ | 197 | 625 | 1030 | 5000+ | -- | 34 | -- |  |  |
| [illegible] | [illegible] | -- | 4.143 | .548 | .731 | 1.823 | 4.010 | -- | .249 | -- |  |  |
| [illegible] | [illegible] | -- | 676.0 | 692.5 | 686.0 | 675.0 | 691.5 | -- | 678.0 | -- |  |  |
| [illegible] | (-217.0) | -- | (217.5) | (-211.0) | (-207.5) | (-218.5) | (-202.0) | -- | (-215.5) | -- |  |  |

Note: Total Initial Budget - 893.5 ($1000's)

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## Validity Evaluation of the Relaxed Model

<Figure 17> and <Figure 18> contain the analysis of variance results concerning the mean values for criterion weight membership. As might be expected due to the diverse membership of the many solution sets formed under relaxation, statistical significance is not as controlled and patterned as the restricted modeling outcomes.

## Reliability Evaluation of the Relaxed Model

Because of the seventeen different solution sets formed by optimization within the relaxed setting, post hoc assessments of consistency were undertaken in a different fashion than those under restricted optimality. As <Figure 19> and <Figure 20> demonstrate for maximization and minimization respectively, the frequency of a unit's selection as a solution was utilized for discriminant analysis. Such a choice to utilize frequency obviously increased the interval variance of the dependent variable; and it is thus expected to diminish the extent of re-predictive accuracy.

Maximization discriminants required five of the available ten criteria to predict membership at 70.97 percent accuracy. Correspondingly, the minimization discriminants required six criterion indicators to re-predict at 83.87 accuracy.

Figure 17. Tests for Level of Satisfactory Significant Differences Between Objects of Budget Revision (Included) and Dellocated Budgets (Excluded); Relaxed Maximization.

(Objective = Maximization)

| Criterion Constraint | CERT | CLAS | BENE | SUPL | INST | CONT | TRAV | CAPI | PERC | COMP | [$N_C$ ($p \le .10$)] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Varying Focus of Cyclical Objective Function | | | | | | | | | | |
| Certificated Salaries | P= .00<br>I=40.4<br>X= 6.1 | P= .17<br>I=27.3<br>X=14.4 | P= .08<br>I=30.2<br>X=13.4 | P= .19<br>I=26.4<br>X=14.3 | P= .05<br>I=31.3<br>X=12.9 | P= .14<br>I=24.2<br>X=16.3 | P= .02<br>I=32.4<br>X=11.2 | P= .14<br>I=28.0<br>X=13.9 | P= .24<br>I=25.8<br>X=14.7 | P= .20<br>I=26.8<br>X=14.7 | [ 4 ] |
| Classified Salaries | P= .25<br>I=22.1<br>X=12.3 | P= .00<br>I=35.5<br>X= 3.9 | P= .01<br>I=30.4<br>X= 8.3 | P= .06<br>I=17.1<br>X=15.4 | P= .47<br>I=20.5<br>X=13.7 | P= .57<br>I=18.5<br>X=14.6 | P= .23<br>I=22.8<br>X=11.3 | P= .23<br>I=22.9<br>X=11.3 | P= .59<br>I=13.3<br>X=15.2 | P=.07<br>I=26.0<br>X= 9.9 | [ 3 ] |
| Employee Benefits | P= [illegible]<br>I=16.7<br>X=13.7 | P= .09<br>I=21.7<br>X= 7.5 | P= .00<br>I=28.7<br>X= 4.1 | P= .81<br>I=11.8<br>X=13.9 | P= .71<br>I=15.1<br>X=11.3 | P= .97<br>I=12.8<br>X=13.1 | P= .87<br>I=13.9<br>X=12.5 | P= .52<br>I=16.4<br>X=10.8 | P= .47<br>I= 9.5<br>X=15.6 | P= .32<br>I=18.2<br>X= 9.7 | [ 2 ] |
| Supplies & Materials | P= [illegible]<br>I=[illegible]<br>X=15.3 | P= .14<br>I=31.5<br>X=17.2 | P= .05<br>I=35.0<br>X=16.0 | P= .00<br>I=47.4<br>X= 4.9 | P= .02<br>I=37.5<br>X=14.6 | P= .00<br>I=40.1<br>X=11.7 | P= .22<br>I=30.1<br>X=13.1 | P= [illegible]<br>I=34.9<br>X=15.0 | P= .52<br>I=35.5<br>X=13.5 | P= .12<br>I=31.8<br>X=17.0 | [ 7 ] |
| Instructional Supplies | P= .02<br>I=30.6<br>X= 4.7 | P= .12<br>I=[illegible]6.5<br>X=12.3 | P= .05<br>I=29.7<br>X=11.2 | P= .05<br>I=29.2<br>X=10.2 | P= .03<br>I=43.3<br>X= 3.7 | P= .16<br>I=26.2<br>X=12.4 | P= .00<br>I=36.2<br>X= 6.2 | P= .16<br>I=25.8<br>X=12.7 | P= .02<br>I=29.6<br>X= 9.2 | P= .08<br>I=27.7<br>X=11.5 | [ 7 ] |
| Contractural Services | P= [illegible]<br>I=20.9<br>X=23.9 | P= .36<br>I=21.7<br>X=23.4 | P= .76<br>I=24.7<br>X=21.6 | P= .81<br>I=24.1<br>X=21.7 | P= .99<br>I=22.8<br>X=22.7 | P= .00<br>I=39.6<br>X=11.9 | P= .32<br>I=16.3<br>X=26.5 | P= .23<br>I=29.2<br>X=13.6 | P= .35<br>I=22.5<br>X=22.9 | P= .53<br>I=26.1<br>X=20.6 | [ 1 ] |
| Travel Expenditures | P= .75<br>I= 4.2<br>X= 2.6 | P= .75<br>I= 4.2<br>X= 2.6 | P= .57<br>I= 4.5<br>X= 2.5 | P= .82<br>I= 3.8<br>X= 2.8 | P= .05<br>I= 9.1<br>X= 0.0 | P= .75<br>I= 4.2<br>X= 2.5 | P= .07<br>I= 3.3<br>X= 0.0 | P= .75<br>I= 4.2<br>X= 2.6 | P= .32<br>I= 3.3<br>X= 2.8 | P= .75<br>I= 4.2<br>X= 2.5 | [ 2 ] |
| Capital Outlay | P= .00<br>I=51.0<br>X=15.2 | P= .00<br>I= 45.5<br>X=18.7 | P= .00<br>I=47.8<br>X=18.8 | P= .04<br>I=40.5<br>X=20.8 | P= .02<br>I=43.2<br>X=21.4 | P= .00<br>I=48.5<br>X=16.8 | P= .01<br>I=43.4<br>X=20.1 | P= .00<br>I=55.0<br>X=12.6 | P= .05<br>I=39.5<br>X=21.5 | P= .01<br>I=44.4<br>X=19.5 | [ 10 ] |
| Administrative Perception | P= .91<br>I=49.8<br>X=51.2 | P= .73<br>I=49.2<br>X=50.5 | P= .59<br>I=51.3<br>X=49.3 | P= .02<br>I=45.2<br>X=53.5 | P= .33<br>I=49.5<br>X=50.3 | P= .61<br>I=48.9<br>X=50.7 | P= .36<br>I=49.6<br>X=50.2 | P= .62<br>I=49.5<br>X=50.3 | P= .05<br>I=46.2<br>X=52.8 | P= .56<br>I=48.7<br>X=50.6 | [ 2 ] |
| Budgetary Composites | P= .00<br>I=57.8<br>X=10.5 | P= .00<br>I=57.1<br>X=10.9 | P= .00<br>I=63.6<br>X= 9.7 | P= .00<br>I=53.3<br>X=11.1 | P= .00<br>I=62.2<br>X=13.7 | P= .00<br>I=57.0<br>X=11.0 | P= .00<br>I=57.8<br>X=10.5 | P= .00<br>I=56.3<br>X=11.5 | P= .00<br>I=52.0<br>X=12.1 | P= .00<br>I=58.3<br>X=10.2 | [ 10 ] |
| [$N_R$ ($p \le .10$)] | [ 5 ] | [ 4 ] | [ 7 ] | [ 5 ] | [ 6 ] | [ 4 ] | [ 5 ] | [ 3 ] | [ 5 ] | [ 4 ] | |

Cell Entries: (P=) = Statistical significance of mean differences, include vs. exclude.
(I=) = Mean budget amount for included object of budget revision.
(X=) = Mean budget amount for excluded object of budget revision.

$N_C$($p \le .10$) # of $p \le .10$ occurrences, where criterion constraint values reflect desireable mean-value weights across the cyclic objective functions.

$N_R$($p \le .10$) # of $p \le .10$ occurrences, where each defined objective function produced desireable mean-value weights across the criterion constraints.

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Figure 18. Tests for Level of Satisfactory Significant Differences Between Objects of Budget Revision (Included) and Dellocated Budgets (Excluded); Relaxed Maximization.

(Objective = Maximization)

| Criterion Constraint | CERT | CLAS | BENE | SUPL | INST | CONT | TRAV | CAPI | PERC | COMP | [$M_C$ ($p \leq .10$)] |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Varying Focus of Cyclical Objective Function |  |  |  |  |  |  |  |  |  |  |
| Certificated Salaries | P= .99<br>I=19.4<br>X=19.1 | --<br>--<br>-- | P= .38<br>I=24.5<br>X=16.2 | P= .02<br>I=32.1<br>X=11.3 | P= .27<br>I=25.4<br>X=15.0 | P= .03<br>I=31.7<br>X=11.6 | P= .02<br>I=32.1<br>X=14.3 | --<br>--<br>-- | P= .02<br>I=34.4<br>X=12.2 | --<br>--<br>-- | [ 4 ] |
| Classified Salaries | P= .13<br>I=23.5<br>X=11.5 | --<br>--<br>-- | P= .29<br>I=10.2<br>X=19.9 | P= .21<br>I=23.2<br>X=11.7 | P= .09<br>I=24.8<br>X= 9.9 | P= .04<br>I=27.1<br>X= 9.2 | P= .73<br>I=18.1<br>X=14.9 | --<br>--<br>-- | P= .35<br>I=22.2<br>X=13.2 | --<br>--<br>-- | [ 2 ] |
| Employee Benefits | P= .32<br>I=18.2<br>X= 9.7 | --<br>--<br>-- | P= .47<br>I= 9.2<br>X=15.4 | P= .39<br>I=17.5<br>X=10.2 | P= .66<br>I=15.2<br>X=11.4 | P= .39<br>I=17.5<br>X=10.2 | P= .59<br>I=13.7<br>X=12.5 | --<br>--<br>-- | P= .70<br>I=15.4<br>X=11.9 | --<br>--<br>-- | -- |
| Supplies & Materials | P= .02<br>I=36.4<br>X=14.1 | --<br>--<br>-- | P= .01<br>I=38.0<br>X=13.1 | P= .65<br>I=25.4<br>X=21.0 | P= .04<br>I=34.1<br>X=14.5 | P= .04<br>I=34.7<br>X=15.2 | P= .03<br>I=35.3<br>X=14.8 | --<br>--<br>-- | P=.00<br>I=47.5<br>X=10.9 | --<br>--<br>-- | [ 6 ] |
| Instructional Supplies | P= .12<br>I=25.5<br>X=12.3 | --<br>--<br>-- | P= .09<br>I=27.3<br>X=11.7 | P= .03<br>I=27.5<br>X=11.6 | P= .52<br>I=20.5<br>X=15.3 | P= .02<br>I=30.3<br>X= 9.5 | P= .10<br>I=27.0<br>X=11.9 | --<br>--<br>-- | P= .00<br>I=36.7<br>X= 8.3 | --<br>--<br>-- | [ 5 ] |
| Contractual Services | P= .25<br>I=29.2<br>X=11.6 | --<br>--<br>-- | P= .58<br>I=26.1<br>X=20.5 | P= .25<br>I=29.5<br>X=18.4 | P= .27<br>I=28.9<br>X=13.3 | P= .30<br>I=16.5<br>X=26.6 | P= .38<br>I=26.1<br>X=20.6 | --<br>--<br>-- | P= .21<br>I=31.3<br>X=18.6 | --<br>--<br>-- | -- |
| Travel Expenditures | P= .75<br>I= 4.2<br>X= 2.5 | --<br>--<br>-- | P= .07<br>I= 8.3<br>X= 0.0 | P= .75<br>I= 4.2<br>X= 2.6 | P= .82<br>I= 3.8<br>X= 2.8 | P= .75<br>I= 4.2<br>X= 2.6 | P= .75<br>I= 4.2<br>X= 2.5 | --<br>--<br>-- | P= .5[illegible]<br>I= 5.0<br>X= 2.4 | --<br>--<br>-- | [ 1 ] |
| Capital Outlay | P= .00<br>I=46.6<br>X=19.1 | --<br>--<br>-- | P= .08<br>I=39.4<br>X=22.6 | P= .01<br>I=44.4<br>X=19.4 | P= .00<br>I=46.0<br>X=16.9 | P= .00<br>I=45.0<br>X=19.0 | P= .00<br>I=51.3<br>X=15.1 | --<br>--<br>-- | P= .00<br>I=52.7<br>X=17.9 | --<br>--<br>-- | [ 7 ] |
| Administrative Perception | P= .40<br>I=43.1<br>X=51.2 | --<br>--<br>-- | P= .14<br>I=46.7<br>X=52.1 | P= .53<br>I=48.6<br>X=50.8 | P= .05<br>I=46.0<br>X=52.9 | P= .28<br>I=47.6<br>X=51.5 | P= .50<br>I=43.8<br>X=50.8 | --<br>--<br>-- | P= .49<br>I=48.2<br>X=50.3 | --<br>--<br>-- | [ 1 ] |
| Budgetary Composites | P= .00<br>I=56.4<br>X=11.4 | --<br>--<br>-- | P= .00<br>I=52.8<br>X=13.7 | P= .00<br>I=56.9<br>X=11.1 | P= .00<br>I=52.8<br>X=11.5 | P= .00<br>I=56.3<br>X=11.5 | P= .00<br>I=57.6<br>X=10.6 | --<br>--<br>-- | P= .00<br>I=67.8<br>X=10.3 | --<br>--<br>-- | [ 7 ] |
| [$M_O$ ($p \leq .10$)] | [ 3 ] | -- | [ 5 ] | [ 4 ] | [ 5 ] | [ 6 ] | [ 5 ] | -- | [ 5 ] | -- |  |

Cell Entries: (P=) = Statistical significance of mean differences, include vs. exclude.
(I=) = Mean budget amount for included object of budget revision.
(X=) = Mean budget amount for excluded object of budget revision.

$M_C$ ($p \leq .10$) # of $p \leq .10$ occurrences, where criterion constraint values reflect desireable mean-value weights across the cyclic objective functions.

$M_O$ ($p \leq .10$) # of $p \leq .10$ occurrences, where each defined objective function produced desireable mean-value weights across the criterion constraints.

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Figure 19. Use of Discriminant Analysis for Predicting the Frequency of Budget Selection Resulting from a Cyclic Maximization of the Relaxed Problem.

| BUDGET | FREQ | BUDGET | FREQ | BUDGET | FREQ | BUDGET | FREQ |
|---|---|---|---|---|---|---|---|
| 01 | 10 | 09 | 10 | 17 | 10 | 25 | -- |
| 02 | 7 | 10 | 1 | 18 | 2 | 26 | 4 |
| 03 | 5 | 11 | 6 | 19 | 1 | 27 | 1 |
| 04 | 10 | 12 | -- | 20 | -- | 28 | 2 |
| 05 | 8 | 13 | 2 | 21 | 2 | 29 | 1 |
| 06 | 6 | 14 | 1 | 22 | 1 | 30 | 1 |
| 07 | 9 | 15 | 10 | 23 | 6 | 31 | 1 |
| 08 | -- | 16 | 4 | 24 | -- | | |

Summary of Criterion Value in Discriminating Selection Frequencies:

| STEP | ENTERED | REMOVED | NOT USED |
|---|---|---|---|
| 1 | Budgetary Composites | | Certificated Salaries |
| 2 | Instructional Supplies | | Employee Benefits |
| 3 | Employee Benefits | | Supplies and Materials |
| 4 | Capital Outlay | | Contractual Services |
| 5 | Administrative Perception | | Travel Expenditures |
| 6 | Classified Salaries | | |
| 7 | | Employee Benefits | |

Classification Results from Predictive Validation:

| Actual Group | (n) | 0 | 1 | 2 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | (6) | 4 (66.7) | 1 (16.7) | 1 (16.7) | -- | -- | -- | -- | -- | -- | -- |
| 1 | (7) | 1 (14.3) | 5 (71.4) | 1 (14.3) | -- | -- | -- | -- | -- | -- | -- |
| 2 | (4) | 1 (25.0) | 1 (25.0) | 2 (50.0) | -- | -- | -- | -- | -- | -- | -- |
| 4 | (2) | -- | -- | -- | 2 (100.0) | -- | -- | -- | -- | -- | -- |
| 5 | (1) | -- | -- | -- | -- | 1 (100.0) | -- | -- | -- | -- | -- |
| 6 | (3) | -- | -- | -- | -- | -- | 1 (66.7) | -- | -- | 1 (33.3) | -- |
| 7 | (1) | -- | -- | -- | -- | -- | -- | 1 (100.0) | -- | -- | -- |
| 8 | (1) | -- | -- | -- | -- | -- | -- | -- | 1 (100.0) | -- | -- |
| 9 | (1) | -- | -- | -- | -- | -- | -- | -- | -- | 1 (100.0) | -- |
| 10 | (5) | -- | -- | -- | -- | -- | -- | 1 (20.0) | 1 (20.0) | -- | 3 (60.0) |

Percent of grouped cases currently classified: 70.97

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Figure 20. Use of Discriminant Analysis for Predicting the Frequency of Budget Selection Resulting from a Cyclic Minimization of the Relaxed Problem.

| BUDGET | FREQ | BUDGET | FREQ | BUDGET | FREQ | BUDGET | FREQ |
|---|---|---|---|---|---|---|---|
| 01 | 7 | 09 | 5 | 17 | 7 | 25 | -- |
| 02 | 5 | 10 | -- | 18 | 4 | 26 | 4 |
| 03 | 3 | 11 | 5 | 19 | -- | 27 | -- |
| 04 | 7 | 12 | -- | 20 | -- | 28 | 1 |
| 05 | 5 | 13 | 1 | 21 | 1 | 29 | -- |
| 06 | 4 | 14 | -- | 22 | 1 | 30 | -- |
| 07 | 6 | 15 | 7 | 23 | 3 | 31 | 2 |
| 08 | -- | 16 | 5 | 24 | -- | | |

Summary of Criterion Value in Discriminating Selection Frequencies:

| STEP | ENTERED | REMOVED | NOT USED |
|---|---|---|---|
| 1 | Budgetary Composites | | Certificated Salaries |
| 2 | Employee Benefits | | Classified Salaries |
| 3 | Contractual Services | | Instructional Supplies |
| 4 | Travel Expenditures | | Administrative Perception |
| 5 | Capital Outlay | | |
| 6 | Supplies and Materials | | |

Classification Results from Predictive Validation:

| Actual Group | (N) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | (11) | 9 (81.8) | 1 ( 9.1) | 1 ( 9.1) | -- | -- | -- | -- | -- |
| 1 | (4) | 1 (25.0) | 3 (75.9) | -- | -- | -- | -- | -- | -- |
| 2 | (1) | -- | -- | 1 (100.0) | -- | -- | -- | -- | -- |
| 3 | (2) | -- | -- | -- | 2 (100.0) | -- | -- | -- | -- |
| 4 | (3) | -- | -- | -- | -- | 3 (100.0) | -- | -- | -- |
| 5 | (5) | -- | -- | -- | -- | 1 (20.0) | 3 (60.0) | 1 (20.0) | -- |
| 6 | (1) | -- | -- | -- | -- | -- | -- | 1 (100.0) | -- |
| 7 | (4) | -- | -- | -- | -- | -- | -- | -- | 4 (100.0) |

Percent of grouped cases currently classified: 83.87

# COMPARISON OF THE RESTRICTED VS. RELAXED DECISIONING FRAMEWORK

Modeling within the restricted setting produced the most 're-predictable' and criterion-significant results. Less criterion measures were required to explain the solution set membership. And, restricted optimizations tended to require no greater modeling effort than the relaxed setting (measured via iterations and computation seconds).

Results of the relaxed setting, however, provide a strong preview of the flexibility of the model for determining a wide array of solution memberships based upon varying standards (objective function values). In addition, the relaxed setting also presents a hint of the diversity in model building based upon the weighting of particular criterion indicators by relaxing certain RHS-values while retaining others in a restrictive fashion.

Finally, both optimality sequences demonstrate the utility of the MAM system in general (and the ROLBAK system in particular) for evaluating multiple criteria, and selecting a distinct solution set from among multiple competing alternatives.

## Effect of the Restricted Environment Upon Optimality

The restricted environment which constrained the ROLBAK decision-making was constructed using an expected solution index (ESI) of value 16; and a perceived expendability value of 500. That is, the design of the solution set (program units to be funded, for a total new budget between 675.0 and 700.0 (1000's dollars); and reflecting an administrative perception of priority for expendability -- was required to exhibit the qualities of potential solution with 16 possible "average" member units for each of the 8 object expenditure categories modeling the individual programmatic budgets. Sequentially, each constraint was cycled through the model as the objective function (first for maximization, then for minimization) in order to differentially direct the construction of the solution sets under optimality; that is, those solution sets which best represented the constrained environment design by the restricted, linear inequality constraints, and furthermore provided the most maximal (or minimal) summation of the objective function vector.

*Optimality under maximization*. Utilizing restricted RHS-value(s) vectors to construct a feasiblity region for ROLBAK decision-making, 2 distinct solution sets were formulated by separate sets of 5 of the available 10 cyclic objective functions. Solution #1:

[ 1 2 3 4 5 7 9 11 15 17 ]

presented 10 program unit budgets for funding under the reduced budgetary levels, out of the existing 31 potential multiple alternatives. The 5 object expenditure (budgeting) vectors which produced these solutions under maximization were:

1. CERT (certificated salaries);
2. CLAS (classified salaries);
3. SUPL (supplies and materials);
4. TRAV (travel expnditures); and
5. CAPI (capital outlay).

A total of 213.5 (1000's dollars) was cut from the original budget of 893.5 (1000's dollars), deallocating 21 program units, resulting in a new, system operating level of 680.0 (1000's dollars). The other distinct solution set constructed under maximization, solution #2:

[ 1  2  4  5  7  11  15  16  17  23 ]

also presented 10 program unit budgets for continued funding, out of the potential 31 alternatives available. The remaining 5 object expenditure vectors which produced these solutions under maximization, were:

1. BENE (employee benefits);
2. INST (instructional materials);
3. CONT (contractual services):
4. PERC (administrative perception); and
5. COMP (budgetary composites).

A total of 213.0 (1000's dollars) was cut from the original budget of 893.5 (1000's dollars), deallocating 21 program units, resulting in a new, system operating level of 680.5 (1000's dollars). Thus the difference between the two solution sets was approximately .5 (1000's dollars) and 4 varying unit member slips.

Optimality under minimization. Utilizing restructed RHS-value(s) vectors to construct the feasibility region for ROLBAK decision-making, the same 2 distinct solution set were found under minimization, as were developed under maximization. Differences were observed however, both in the number of occurrences of the solution set, and in the objective function(s) which guided the solutional design. Solution #1:

[ 1  2  3  4  5  7  9  11  15  17 ]

resulted from the following 4 objective function vectors:

1. BENE (employee benefits);
2. INST (instructional materials);
3. CONT (contractual services); and
4. PERC (administrative perception).

The reader will note, that under maximization, these same four vectors collaborated on a different solution set. The resulting expenditure reduction of 213.5 (1000's dollars) remains the same, of course. Solution #2 under minimization:

[ 1 2 4 5 7 11 15 16 17 23 ]

occurred in 3 instances; under the use of the cyclic objective functions:

1. CLAS (classified salaries);
2. SUPL (supplies and materials); and
3. CAPI (capital outlay).

The reader will also note, that previously under maximization, these same three vectors collaborated on a different solution set. As before, the resulting expenditure reduction of 213.0 (1000's dollars) remains the same.

*Validity analysis of restricted results*. For the purposes of this study, validity tests represented the administration of post hoc analysis to determine if the resulting solutions reflected the original objectives of the ROLBAK model. The original ROLBAK objectives were formulated via the construction of the linear 'object category' vectors. Validation under these circumstances proceeds in two stages. Stage 1 validation is moot, since the executed ROLBAK model produced at least one solution vector (in our case, two distinct alternative solution sets), in conformance with pre-defined RHS-vector values. Stage

2 validation proceeds to analyze the values of the various constraint vectors; and to test their mean-differences determined by their solution versus the non-solution membership. Parametric, oneway analysis of variance procedures were utilized to test these criterion, mean-value differences. Solution #1:

$$[\ 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 7 \quad 9 \quad 11 \quad 15 \quad 17\ ]$$

demonstrated 6 of the 10 criterion vectors to produce statistically significant ($p \leq .10$) greater criterion mean-weights for the solution sets, then existing within the non-solution set. The six criterion vectors were:

1. CERT (certificated salaries);
2. CLAS (classified salaries);
3. SUPL (supplies and materials);
4. INST (instructional materials);
5. CAPI (capital outlay); and
6. COMP (budgetary composites).

Of the remaining 4 vectors, employee benefits (BENE), contractual services (CONT), and travel expenditures (TRAV), the lack of $p \leq .10$ significance is not viewed as an indication of potential invalidity, due to the mean-trends observed. The relatively confounded p-level for administrative perception (PERC) of $p = .67$, is understandable based upon the ordinal scaling for PERC, in which each ordinal graduation (1, 2, 3, ..., 31) is represented. Similarly, solution #2 is:

$$[\ 1 \quad 2 \quad 4 \quad 5 \quad 7 \quad 11 \quad 15 \quad 16 \quad 17 \quad 23\ ]$$

demonstrated 5 of the 10 criterion vectors to produce statistically-significant ($p \leq .10$) greater criterion mean-weights for the solution set. These five criterion vectors were:

1. SUPL (supplies and materials);
2. INST (instructional materials);
3. CONT (contractual services);
4. CAPI (capital outlay); and
5. COMP (budgetary composites).

The remaining five criterion mean weights are acceptable, though not at the desired $p \leq .10$ level. Much of the inability to gain the desirable $p \leq .10$ level can be attributed to the large proportion of zero-cells (scant index) within the constraint matrix.

*Reliability analysis of restricted results*. For the purposes of this study, reliability tests represented the administration of post hoc analyses to determine if the resulting solutions were 'predictable' based upon the multiple data distribution configurations of the criterion vectors; that is, whether a particular program unit's inclusion (versus exclusion) within the solution set was predictable. Parametric discriminant function analysis procedures were utilized to evaluate the extent of such predictability. In order to predict the original solution set #1:

$$[\ 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 7 \quad 9 \quad 11 \quad 15 \quad 17\ ]$$

a total of 5 criterion distributions were required. Listed in the order of their importance (i.e., amount of variance explained and order of entry into discriminant construction), these criteria are:

1. COMP (budgetary composites);
2. SUPL (supplies and materials);
3. CAPI (capital outlay);
4. CERT (certificated salaries); and
5. CLAS (classified salaries).

The discriminant re-prediction (reclassification of solution set membership) resulted in 1 mis-inclusion for a final 96.77 percent accuracy (repredicability) factor. In turn, solution #2:

[ 1 2 4 5 7 11 15 16 17 23 ]

required the following 3 criterion distributions in order to predict membership within the solution set (in order of importance/entry):

1. COMP (budgetary composites);
2. CONT (contractual services); and
3. INST (instructional materials).

The discriminant re-prediction for the second solution formed upon restricted optimality resulted in 1 mis-exclusion for a final 96.77 percent accuracy factor. The reader will note, that the criterion distribution COMP was the only vector utilized in both discriminant formulizations.

Non-solution results. While maximization (optimality) produced a solution set for each cyclic iteration of the various criterion vectors, minimization was unable to produce a solution vector, when the criterion vectors being 'minimized' were the 3 vectors:

1. CERT (certificated salaries);
2. TRAV (travel expenditures); and
3. COMP (budgetary composites).

Non-solutions based upon TRAV can be discounted based upon the high proportion of zero-cell entries (29 of 31 possible cells equal to 0); in which case, the model could not 'make up its mind'. Non-optimality under the guidance of CERT and/or COMP however, is an interesting result. Precisely stated (and hopefully in English), neither the CERT nor the COMP vector(s) could summate to a small enough final value (minimum), such that the optimal objective function vector could physically pass-through the feasibility region geometrically constructed via the 11 constraint matrix inequalities. (The authors apologize for the last statement!)

## Effect of the Relaxed Environment Upon Optimality

The relaxed environment which constrained the ROLBAK decision-making was constructed using an expected solution index (ESI) of value 10; and a perceived expendability value of 600. That is, the design of the solution set was required to exhibit the qualities of potential solution with 10 possible "average" member units for each of the 8 object categories used in constraints. The reader will note, that since the RHS-value for administrative perception (PERC) was increased to value 600, program units with greater 'perceived expendability' levels could still become members of the solution set -- that is, refunded for continuation. As with the restricted environment discussed in the preceding section, each constraint was cycled through the relaxed model (sequentially) as the objective function.

Optimality under maximization. ROLBAK produced a distinct solution set for each of the 10 cyclical objective functions utilized during optimal maximization of the relaxed model. In fact, only the program units:

[ 8 12 20 24 25 31 ]

were never included in at least one of the 10 individual solution vectors. Budgetary savings ranged from a low of 193.5 (1000's dollars) for the solution vector:

[ 1 4 5 7 9 11 16 17 23 26 29 ],

to a high of 218.0 (1000's dollars) for each of the solutions:

[ 1 2 3 4 6 7 9 11 15 16 17 23 ]

based upon maximal CAPI (capital outlay), and:

[ 1 4 5 6 7 9 [illegible]4 15 16 17 18 23 28 ]

based upon maximal PERC (administrative perception). The size of the solution vectors ranged from a low of 11 units to a high of 13 units (as compared to the stable 10 units under optimality in the restricted system).

Optimality under minimization. A total of 7 optimal solution vectors, each distinct, resulted from minimization within the constrained, relaxed space. The criterion vectors producing optimal results were:

1. CERT (certificated salaries);
2. SUPL (supplies and materials);
3. INST (instructional materials);
4. CONT (contractual services);
5. TRAV (travel expenditures);
6. PERC (administrative perception); and
7. BENE (employee benefits).

Programmatic savings ranged from a low of 202.0 (1000's dollars) based upon TRAV:

[ 1 4 5 6 7 11 15 16 17 21 26 ]

to a high of 218.5 (1000's dollars) based upon CONT:

[ 1 2 3 4 6 7 9 15 17 18 23 26 ].

Unit membership ranged from a high of *13* (INST) to a low of *10* (PERC). Not one of *7* solutions under minimization was identical to the *10* solutions under maximization.

*Validity analysis of relaxed results*. The approach to validating the results of th ROLBAK execution under relaxed conditions differed from that previously discussed within the restricted state. Since *17* distinct solution sets were formed based upon both maximization and minimization under relaxed conditions, validation of the effect of solution set construction upon individual criterion mean-weight differences was effected in two related ways. *First*, the frequency of $p \leq .10$ occurrences, where each defined objective function (CERT, CLAS, ..., COMP) produced desireable mean-value weights across the criterion constraints was explored, utilizing (as before) oneway analysis of variance procedures. These results are indicated as:

$$[\ N_R\ (p \leq .10)\ ].$$

Secondly, the frequence of $p \leq .10$ occurrences, where criterion constraint values (CERT, CLAS, ..., COMP) reflect desireable mean-value weights across the cyclic objective functions, were studied; and indicated as:

$$[\ N_C\ (p \leq .10)\ ].$$

<Figure 21> summarizes these $N_R$ and $N_C$ summations for optimality results under both maximization and minimization. The $N_R$-frequencies are analogous to those previously defined for the restricted environment. Based upon the computed percents for the total frequencies possible, *10* and *7* (for maximization and minimization, respectively), the $N_R$ values appear relatively

Figure 21. Summary of [ $N_R(p \le .10)$ ] and [ $N_C(p \le .10)$ ] Values from Figures 19 and 20.

| | [ Objective Functions ($N_R$) ] ... [ Criterion Constraints ($N_C$) ] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CERT | CLAS | BENE | SUPL | INST | CONT | TRAV | CAPI | PERC | COMP |
| Maximization | | | | | | | | | | |
| [ $N_R(p \le .10)$ ] | 5 | 4 | 7 | 5 | 6 | 4 | 5 | 3 | 5 | 4 |
| PCT (TOT=10) | 50.0 | 40.0 | 70.0 | 50.0 | 60.0 | 40.0 | 50.0 | 30.0 | 50.0 | 40.0 |
| [ $N_C(p \le .10)$ ] | 4 | 3 | 2 | 7 | 7 | 1 | 2 | 10 | 2 | 10 |
| PCT (TOT=10) | 40.0 | 30.0 | 20.0 | 70.0 | 70.0 | 10.0 | 20.0 | 100.0 | 100.0 | |
| Minimization | | | | | | | | | | |
| [ $N_R(p \le .10)$ ] | 3 | -- | 5 | 4 | 5 | 6 | 5 | -- | 5 | -- |
| PCT (TOT=7) | 42.9 | -- | 71.5 | 57.2 | 71.5 | 85.3 | 71.5 | -- | 71.5 | -- |
| [ $N_C(p \le .10)$ ] | 4 | 2 | -- | 6 | 5 | -- | 1 | 7 | 1 | 7 |
| PCT (TOT=7) | 57.2 | 28.6 | -- | 35.3 | 71.5 | -- | 14.3 | 100.0 | 14.3 | 100.0 |
| Sum ($N_R$) | 8 | 4 | 12 | 9 | 11 | 10 | 10 | 3 | 10 | 4 |
| [ RANK ] | [7.0] | [8.5] | [1.0] | [6.0] | [2.0] | [4.0] | [4.0] | [10.0] | [4.0] | [8.5] |
| Sum ($N_C$) | 8 | 5 | 2 | 13 | 12 | 1 | 3 | 17 | 3 | 17 |
| [ RANK ] | [5.0] | [6.0] | [9.0] | [3.0] | [4.0] | [10.0] | [7.5] | [1.5] | [7.5] | [1.5] |
| \| DIFF-RANKS \| | 2.0 | 2.5 | 3.0 | [illegible] | 2.0 | 6.0 | 3.5 | 8.5 | 3.5 | 7.0 |

where:

[ $N_R(p \le .10)$ ] = N of $p \le$ occurrences where each defined objective function (CERT, CLAS, ..., COMP) produced desireable mean-value weights across the criterion constraints.

[ $N_C(p \le .10)$ ] = N of $p \le .10$ occurrences, where criterion constraint values (CERT, CLAS, ..., COMP) reflect desireable mean-value weights across the cyclic objective functions.

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identical; likewise for the $N_C$ frequencies. Summing both the $N_R$ and $N_C$ values, and ranking those sums (where 1 = high and 10 = low), an ordinal measure of relative weight can be developed. Finding the absolute value of the difference between these sum ($N_R$) and ($N_C$) ranks (i.e. | DIFF-RANKS | ), presents a measure of relative consistency between $N_R$ and $N_C$ values. The authors have previously thought that the greater the consistency, the greater the resulting value of the particular criterion vector. Thus, the smaller the rank-difference, the more valuable the criterion involved. However, careful examination of the ranks of $N_R$ and $N_C$ demonstrate that the correlation between the two vectors of rank to be non-parallel (correlation ($N_R$, $N_C$) = -0.666). And furthermore, that the correlation between the $N_R$ and $N_C$ values, and their difference (DIFF-RANKS) to be nearly non-existent (+0.129 and -0.048, respectively). Further study is required in this area to study these issues of consistency and utility.

Reliability analysis of relaxed results. As with restricted results, discriminant functions were utilized to determine the predictablity of the obtained solution vectors. For the relaxed environment however, membership in any particular solution set was not the dependent variable; rather, the frequency of each individual program unit being chosen for refunding across all criterion objective functions (i.e. the selection tally for the tracking matrix) was used as the dependent (to be predicted) variable. Under maximization, the re-prediction of the selection frequency (i.e. the N of inclusion across 10 successful executions) required 5 criterion distributions to formulate the discriminant functions. In order of entry and importance, they were:

1. COMP (budgetary composites);
2. INST (instructional materials);
3. CAPI (capital outlay);

4. PERC (administration perception); and
5. CLAS (classified salaries).

The discriminant re-prediction (reclassification of total inclusion frequency) resulted in 4 over-estimates and 5 underestimates for a final 70.97 percent accuracy (repredictability) factor. Minimization results on the other hand required 6 criterion distributions to formulate the discriminant functions:

1. COMP (budgetary composites);
2. BENE (employee benefits);
3. CONT (contractual services);
4. TRAV (travel expenditures);
5. CAPI (capital outlay); and
6. SUPL (suplies and materials).

Discriminant re-prediction yielded 3 over-estimates and 2 underestimates for a total accuracy factor of 83.87 percent. It would seem, that the criterion distributions are much more useful in predicting individual inclusion, then in determining total inclusion across all criterion objective functions.

*Non-solution results*. As was evidenced in the restricted environment results, only minimization within a relaxed region produced instances (3) of non-solution; they were:

1. CLAS (classified salaries);
2. CAPI (capital outlay); and
3. COMP (budgetary composites).

# VALIDATION OF THE ROLBAK MODELING FRAMEWORK

A total of *31* program budgeting (unit) alternatives were evaluated for defunding across a total of *10* competing criterion references. In lieu of a step-wise procedure as represented in the school closure modeling framework, the model is further constrained to choose those programs for refunding such that the new operating district budget is not less than *675,000* dollars, but not more than *700,000* dollars for the particular programs under scrutiny. To study the effect of the model's solution generation process, the feasibility region as defined by the constraint matrix and the RHS-values is constructed in two distinct patterns: a highly *restricted* region in which very stringent controls are defined for the modeling procedure; and a relatively *relaxed* region in which less stringent controls are modeled. In addition, the ROLBAK formulation is executed both for cyclic maximization of the objective functions, and for cyclic minimization of the objective functions. Thus, a total of *4* tracking matrice containing *10* potential solution sets (each) result.

This particular modeling application represents the "scant" matrix case, in that a high proportion (48.7 percent) of criterion matrix cells contained a 'zero' entry, signifying no cost for that particular alternative within a specific object-expenditure category. For the SCHCLO model, the criterion matrix was "complete" -- all cells contained a value greater than zero.

Under the 'restricted' formulation, the *17* resulting solution sets signify only *2* distinct solution vectors. In contrast under the 'relaxed' formulation, a total of *17* distinct solution vectors result. Under both restricted and relaxed limitations, *3* objective functions were unable to declare optimality due to the inability to find an initial integer-feasible solution.

<Figure 22> and <Figure 23> display the solution sets resulting from optimization within the restricted region environments. The selection tally vector is noted, as well as the impact upon the total budget based upon the simulated cuts (i.e., where X=funded). As can be easily seen, the solutions resulting from optimization within the restricted environment present only two distinct alternatives for later discriminant analyses.

<Figure 24> and <Figure 25> display those solution sets resulting from the optimizations within a relaxed environment. A total of 17 distinct solution set vectors are formed; and thus the selection tally matrix demonstrates greater variability than existent within the restricted orientation.

Discriminant functions were computed for the relaxed modeling setting first, requiring a separate discriminant execution for each of the distinct solution vectors resulting from the MAM analysis. As noted in an earlier section to this paper, criterion strength was evaluated utilizing the three composites vectors:

DISCRIMINANT CRITERION INCLUSION VECTOR

DISCRIMINANT CRITERION ENTRY VECTOR

DISCRIMINANT WEIGHTING SUMMARY VECTOR.

The first vector is composed of binary (1,0) entries signifying whether a specific criterion was entered into the discriminant analysis for explaining the variance within the solution set. The second vector contains entries of 1,2,3,... , such that the order-of-entry for the discriminant criteria is represented. Finally, the third vector contains a factor-weight

**Effect Upon Budget Deallocation Decisions Based Upon the Variable Flows of a Cyclic Objective Function, and the Interaction of a "Maximized, Restricted" Constraint Iterative Problem.**

**Objective = Maximization  Constraints: Restricted (EXP=16; PERC = 500)**

| Budget Alterna-tives | 01 CERT | 02 CLAS | 03 BENE | 04 SUPL | 05 INST | 06 CONT | 07 TRAV | 08 CAPI | 09 PERC | 10 COMP | SELECTION TALLY | BUDGET AMOUNT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | X | X | X | X | X | X | X | X | X | X | 10 | 87.5 |
| 02 | X | X | X | X | X | X | X | X | X | X | 10 | 44.5 |
| 03 | X | X |  | X |  |  | X | X |  |  | 5 | 34.5 |
| 04 | X | X | X | X | X | X | X | X | X | X | 10 | 71.5 |
| 05 | X | X | X | X | X | X | X | X | X | X | 10 | 70.5 |
| 06 |  |  |  |  |  |  |  |  |  |  | -- | 32.5 |
| 07 | X | X | X | X | X | X | X | X | X | X | 10 | 51.5 |
| 08 |  |  |  |  |  |  |  |  |  |  | -- | 1.5 |
| 09 | X | X |  | X |  |  | X | X |  |  | 5 | 43.0 |
| 10 |  |  |  |  |  |  |  |  |  |  | -- | 4.0 |
| 11 | X | X | X | X | X | X | X | X | X | X | 10 | 54.0 |
| 12 |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| 13 |  |  |  |  |  |  |  |  |  |  | -- | 5.5 |
| 14 |  |  |  |  |  |  |  |  |  |  | -- | 4.0 |
| 15 | X | X | X | X | X | X | X | X | X | X | 10 | 116.0 |
| 16 |  |  | X |  | X | X |  |  | X | X | 5 | 23.0 |
| 17 | X | X | X | X | X | X | X | X | X | X | 10 | 107.0 |
| 18 |  |  |  |  |  |  |  |  |  |  | -- | 13.0 |
| 19 |  |  |  |  |  |  |  |  |  |  | -- | 2.0 |
| 20 |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| 21 |  |  |  |  |  |  |  |  |  |  | -- | 16.0 |
| 22 |  |  |  |  |  |  |  |  |  |  | -- | 10.5 |
| 23 |  |  | X |  | X | X |  |  | X | X | 5 | 55.0 |
| 24 |  |  |  |  |  |  |  |  |  |  | -- | 4.5 |
| 25 |  |  |  |  |  |  |  |  |  |  | -- | 2.5 |
| 26 |  |  |  |  |  |  |  |  |  |  | -- | 19.0 |
| 27 |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| 28 |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| 29 |  |  |  |  |  |  |  |  |  |  | -- | 2.0 |
| 30 |  |  |  |  |  |  |  |  |  |  | -- | 12.0 |
| 31 |  |  |  |  |  |  |  |  |  |  | -- | 2.5 |
|  | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |  |  |
| O.F. Value: | 340.7 | 274.5 | 217.9 | 433.9 | 330.0 | 362.1 | 50.0 | 534.6 | 496.2 | 680.5 |  |  |
| Iteration at Optimality: | 36 | 69 | 76 | 115 | 228 | 27 | 114 | 51 | 5000+ | 369 |  |  |
| Time (Secs): | .266 | .298 | .288 | .325 | .384 | .264 | .383 | .274 | 4.498 | .850 |  |  |
| Roll-Back Savings: | 680.0 | 680.0 | 680.5 | 680.0 | 680.5 | 680.5 | 680.0 | 680.0 | 680.5 | 680.5 |  |  |
| (- Cut) | (-213.5) | (-213.5) | (-213.0) | (-213.5) | (-213.0) | (-213.0) | (-213.5) | (-213.5) | (-213.0) | (-213.0) |  |  |

Note: Total Initial Budget = 893.5 ($1000's)

Figure 10:

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Effect Upon Budget Deallocation Decisions Based Upon the Variable Forms of a Cyclic Objective Function, and the Interaction of a "Minimized, Restricted" Constraint Interative Problem.

Objective = Minimization   Constraints = Restricted (8xP-16; PERC-500)

| Budget Alterna-tives | 01 LERT | 02 CLAS | 03 BENE | 04 SUPL | 05 INST | 06 CONT | 07 TRAV | 08 CAPI | 09 PERC | 10 COMP | SELECTION TALLY | BUDGET AMOUNT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | | X | X | X | X | X | | X | X | | 7 | 87.5 |
| 02 | | X | X | X | X | X | | X | X | | 7 | 44.5 |
| 03 | | | X | | X | X | | | X | | 4 | 34.5 |
| 04 | | X | X | X | X | X | | X | X | | 7 | 71.5 |
| 05 | | X | X | X | X | X | | X | X | | 7 | 70.5 |
| 06 | | | | | | | | | | | -- | 32.5 |
| 07 | | X | X | X | X | X | | X | X | | 7 | 51.5 |
| 08 | | | | | | | | | | | -- | 1.5 |
| 09 | | | X | | X | X | | x | X | | 4 | 43.0 |
| 10 | | | | | | | | | | | -- | 4.0 |
| 11 | | X | X | X | X | X | | X | X | | 7 | 54.0 |
| 12 | | | | | | | | | | | -- | 1.0 |
| 13 | | | | | | | | | | | -- | 5.5 |
| 14 | | | | | | | | | | | -- | 4.0 |
| 15 | | X | X | X | X | X | | X | X | | 7 | 116.0 |
| 16 | | X | | X | | | | X | | | 3 | 23.0 |
| 17 | | X | X | X | X | X | | X | X | | 7 | 107.0 |
| 18 | | | | | | | | | | | -- | 13.0 |
| 19 | | | | | | | | | | | -- | 2.0 |
| 20 | | | | | | | | | | | -- | 1.0 |
| 21 | | | | | | | | | | | -- | 16.0 |
| 22 | | | | | | | | | | | -- | 10.5 |
| 23 | | X | | X | | | | X | | | 3 | 55.0 |
| 24 | | | | | | | | | | | -- | 4.5 |
| 25 | | | | | | | | | | | -- | 2.5 |
| 26 | | | | | | | | | | | -- | 19.0 |
| 27 | | | | | | | | | | | -- | 1.0 |
| 28 | | | | | | | | | | | -- | 1.0 |
| 29 | | | | | | | | | | | -- | 2.0 |
| 30 | | | | | | | | | | | -- | 12.0 |
| 31 | | | | | | | | | | | -- | 2.5 |
| | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | |
| O.F. Value: | -- | 234.5 | 197.0 | 366.8 | 314.8 | 313.0 | -- | 482.6 | 489.0 | -- | | |
| Iteration at Optimality: | -- | 5000* | 686 | 200 | 85 | 902 | -- | 203 | 53 | -- | | |
| Time (sec): | -- | 4.581 | .933 | .563 | .304 | 1.193 | -- | .407 | .256 | -- | | |
| Roll-Back Savings: | -- | 680.5 | 680.0 | 680.5 | 680.0 | 680.0 | -- | 680.5 | 680.0 | -- | | |
| (-Cut) | -- | (-213.0) | (-213.5) | (-213.0) | (-213.5) | (-213.5) | -- | (-213.0) | (-213.5) | -- | | |

Note: Total Initial Budget = 893.5 ($1000's)

Figure 11.

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**Effect Upon Budget Deallocation Decisions Based Upon the Variable Flows of a Cyclic Objective Function, and the Interaction of a "Maximized, Relaxed" Constraint Iterative Problem.**

**Objective = Maximization    Constraints: Relaxed (EXP=10; PERC = 600)**

| Budget Alternatives | 01 CERT | 02 CLAS | 03 BENE | 04 SUPL | 05 INST | 06 CONT | 07 TRAV | 08 CAPI | 09 PERC | 10 COMP | SELECTION TALLY | BUDGET AMOUNT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | X | X | X | X | X | X | X | X | X | X | 10 | 87.5 |
| 02 | X | X | X | X | X | X |  | X |  |  | 7 | 44.5 |
| 03 | X | X | X |  |  |  | X | X |  |  | 5 | 31.5 |
| 04 | X | X | X | X | X | X | X | X | X | X | 10 | 71.5 |
| 05 | X |  | X | X | X | X | X |  | X | X | 8 | 70.5 |
| 06 | X |  |  | X | X |  | X | X | X |  | 6 | 32.5 |
| 07 | X | X |  | X | X | X | X | X | X | X | 9 | 51.5 |
| 08 |  |  |  |  |  |  |  |  |  |  | -- | 1.5 |
| 09 | X | X | X | X | X | X | X | X | X | X | 10 | 43.0 |
| 10 |  |  |  |  |  | X |  |  |  |  | 1 | 4.0 |
| 11 |  | X | X | X |  | X |  | X |  | X | 6 | 54.0 |
| 12 |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| 13 |  |  |  |  | X |  | X |  |  |  | 2 | 5.5 |
| 14 |  |  |  |  |  |  |  |  | X |  | 1 | 4.0 |
| 15 | X | X | X | X | X | X | X | X | X | X | 10 | 116.0 |
| 16 |  |  |  |  |  | X |  | X | X | X | 4 | 23.0 |
| 17 | X | X | X | X | X | X | X | X | X | X | 10 | 107.0 |
| 18 |  |  |  | X |  |  |  |  | X |  | 2 | 13.0 |
| 19 |  | X |  |  |  |  |  |  |  |  | 1 | 2.0 |
| 20 |  |  |  |  |  |  |  |  |  |  | -- | 1.0 |
| 21 | X |  | X |  |  |  |  |  |  |  | 2 | 16.0 |
| 22 |  |  |  |  |  |  |  | X |  |  | 1 | 10.5 |
| 23 |  | X | X |  | X |  | X |  | X | X | 6 | 55.0 |
| 24 |  |  |  |  |  |  |  |  |  |  | -- | 4.5 |
| 25 |  |  |  |  |  |  |  |  |  |  | -- | 2.5 |
| 26 | X | X |  |  |  |  | X |  |  | X | 4 | 19.0 |
| 27 |  |  |  | X |  |  |  |  |  |  | 1 | 1.0 |
| 28 |  |  |  | X |  |  |  |  | X |  | 2 | 1.0 |
| 29 |  |  |  |  |  |  |  |  |  | X | 1 | 2.0 |
| 30 |  |  |  |  |  | X |  |  |  |  | 1 | 12.0 |
| 31 |  |  |  |  |  |  |  |  |  |  | -- | 2.5 |
|  | 12 | 12 | 11 | 13 | 11 | 12 | 12 | 12 | 13 | 12 |  |  |
| O.F. Value | 435.4 | 425.5 | 316.1 | 615.9 | 476.6 | 477.7 | 100.0 | 659.04 | 600.0 | 700.0 |  |  |
| Starting at Optimality: | 20 | 60 | 202 | 16 | 43 | 52 | 163 | 65 | 5000+ | 457 |  |  |
| Time (Sec): | .246 | .359 | .416 | .227 | .297 | .337 | .589 | .310 | 6.022 | 1.166 |  |  |
| Roll-Back Savings: | 685.5 | 685.5 | 699.5 | 693.0 | 684.5 | 684.5 | 693.5 | 675.5 | 675.5 | 700.0 |  |  |
|  | (-204.0) | (-208.0) | (-194.0) | (-200.5) | (-209.0) | (-209.0) | (-200.0) | (-218.0) | (-218.0) | (-193.5) |  |  |

Note: Total Initial Budget 891.5 ($1000's)

Figure 12.

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Effect Upon Budget Deallocation Decisions Based Upon the Variable Flows of a Cyclic Objective. Function, and the Interaction of a "Minimized, Relaxed" Constraint Iterative Problem.

Objective = Minimization    Constraints: Relaxed (EXP=10; PERC = 600)

| Budget Alternatives | 01 LERI | 02 CLAS | 03 BENE | 04 SUPL | 05 INST | 06 CONT | 07 TRAV | 08 CAPI | 09 PERC | 10 COMP | SELECTION TALLY | BUDGET AMOUNT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | X | | X | X | X | X | X | | X | | 7 | 87.5 |
| 02 | X | | | X | X | X | | | X | | 5 | 44.5 |
| 03 | | | | X | X | X | | | | | 3 | 31.5 |
| 04 | X | | X | X | X | X | X | | X | | 7 | 71.5 |
| 05 | | | X | X | X | | X | | X | | 5 | 70.5 |
| 06 | | | X | | | X | X | | X | | 4 | 32.5 |
| 07 | X | | X | X | | X | X | | X | | 6 | 51.5 |
| 08 | | | | | | | | | | | -- | 1.5 |
| 09 | X | | X | | X | X | X | | X | | 5 | 43.0 |
| 10 | | | | | | | | | | | -- | 1.0 |
| 11 | X | | X | | X | | X | | X | | 5 | 51.0 |
| 12 | | | | | | | | | | | -- | 1.0 |
| 13 | | | X | | | | | | | | 1 | 5.5 |
| 14 | | | | | | | | | | | -- | 4.0 |
| 15 | X | | X | X | X | X | X | | X | | 7 | 116.0 |
| 16 | X | | X | X | X | | X | | | | 5 | 73.0 |
| 17 | X | | X | X | X | X | X | | X | | 7 | 107.0 |
| 18 | X | | X | | X | X | | | | | 4 | 13.0 |
| 19 | | | | | | | | | | | -- | 2.0 |
| 20 | | | | | | | | | | | -- | 1.0 |
| 21 | | | | | | | X | | | | 1 | 16.0 |
| 22 | X | | | | | | | | | | 1 | 10.5 |
| 23 | X | | | X | | X | | | | | 3 | 55.0 |
| 24 | | | | | | | | | | | -- | 4.5 |
| 25 | | | | | | | | | | | -- | 2.5 |
| 26 | | | | X | X | X | X | | | | 4 | 19.0 |
| 27 | | | | | | | | | | | -- | 1.0 |
| 28 | | | X | | | | | | | | 1 | 1.0 |
| 29 | | | | | | | | | | | -- | 2.0 |
| 30 | | | | | | | | | | | -- | 12.0 |
| 31 | | | | X | X | | | | | | 2 | 2.5 |
| | 12 | -- | 13 | 12 | 13 | 12 | 12 | -- | 10 | -- | | |
| Optimal Value | 234.5 | -- | 110.0 | 304.7 | 265.9 | 198.3 | 50.0 | -- | 482.3 | -- | | |
| Iteration at Optimality: | 869 | -- | 5000+ | 197 | 625 | 1030 | 5000+ | -- | 34 | -- | | |
| Time (sec): | 1.665 | -- | 4.143 | .548 | .731 | 1.823 | 4.010 | -- | .249 | -- | | |
| Kill-Back Savings: | 676.5 | -- | 676.0 | 682.5 | 686.0 | 675.0 | 691.5 | -- | 678.0 | -- | | |
| (- Cut) | (-217.0) | -- | (217.5) | (-211.0) | (-207.5) | (-218.5) | (-202.0) | -- | (-215.5) | -- | | |

Note: Total Initial Budget = 691.5 ($1000's)

Figure 13.

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entry for each of the 'entered' vectors,—to measure the relative importance of each of the discriminating criterion references.

The notion of decisioning reliability was evaluated utilizing two techniques:

CANONICAL CORRELATION

RE-CLASSIFICATION ANALYSIS.

‹Figure 26› contains the discriminant results for solutions accountable to maximization within a relaxed region. The first ten columns contain the information from the discriminant analyses for each of the ten simulated solution sets. The ordinal numerals represent order-of-entry, while the bracketed entries [x.xx] contain the factor-weights computed from dividing each of the standardized canonical discriminant coefficients by the smallest such coefficient for each discriminant analysis. For example in the first column signifying the results of discriminating the solution computed from maximizing 'certificated salaries', 5 criteria were required to explain available variance within the solution set. The criterion 'budgetary composites' was entered first, and represents a factor of 2.51 in its importance to the remaining 4 criterion discriminants. The criterion 'certificated salaries' was entered secondly, and represents a factor of 3.17 in its relative importance for discriminating the solution set being analyzed; and so forth. The selection tally vector is similarly analyzed via discriminant functions.

For understanding the dimension of decisioning reliability, computed canonical correlation coefficients existed as follows, for maximized-relaxed solutions:

Summary of Criterion Vector Order-of-Entry, in Discriminating the Solution Set Vector for Each Cyclic MAXIMIZATION within a RELAXED Region. (Note: Source of Discriminant Criterion Inclusion Vector; Discriminant Criterion Entry Vector; and Discriminant Weighting Summary Vector)

( VALUE OF OBJECTIVE FUNCTION DURING CYCLIC-OPTIMIZATION EVALUATIONS )

| Criterion Vector | CERT | CLAS | BENE | SUPL | INST | CONT | TRAV | CAPI | PERC | COMP | Selection Tally Vector | Discriminant Function # |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Certificated Salaries | 2<br>[3.17] | 4<br>[1.00] | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Classified Salaries | -- | 2<br>[3.08] | -- | 4<br>[1.57] | -- | -- | -- | -- | 3<br>[2.04] | 2<br>[1.00] | 5 | 5 |
| Employee Benefits | -- | 3<br>[1.48] | 2<br>[2.74] | -- | -- | 5<br>[1.00] | -- | -- | -- | -- | -- | -- |
| Supplies & Materials | 5<br>[1.00] | -- | -- | 1<br>[3.56] | -- | 3<br>[1.21] | -- | 2<br>[1.46] | -- | -- | -- | -- |
| Instructional Materials | -- | -- | 5<br>[1.00] | -- | 1<br>[3.13] | -- | 2<br>[1.78] | 3<br>[1.00] | 4<br>[2.03] | -- | 2 | 2 |
| Contractual Services | 4<br>[2.16] | -- | 3<br>[1.15] | 5<br>[1.00] | -- | 2<br>[1.87] | 3<br>[2.19] | -- | -- | -- | -- | -- |
| Travel Expenditures | -- | -- | -- | -- | 4<br>[1.00] | -- | 4<br>[1.17] | -- | 5<br>[1.00] | -- | -- | -- |
| Capital Outlay | 3<br>[2.40] | -- | 4<br>[1.29] | -- | -- | 4<br>[1.02] | 5<br>[1.00] | 1<br>[3.65] | -- | -- | 3 | 3 |
| Administrative Perception | -- | -- | -- | 3<br>[1.68] | 3<br>[1.25] | -- | -- | -- | 2<br>[2.59] | -- | 4 | 4 |
| Budgetary Composites | 1<br>[2.51] | 1<br>[2.29] | 1<br>[2.91] | 2<br>[3.46] | 2<br>[3.03] | 1<br>[1.71] | 1<br>[2.63] | -- | 1<br>[3.04] | 1<br>[3.67] | 1 | 1 |
| Number of Mis-inclusions | -- | 2 | 2 | 1 | -- | -- | 1 | 2 | 2 | 2 | 4 | Number of Over-Estimates |
| Number of Mis-Exclusions | -- | -- | -- | -- | -- | -- | 1 | -- | 2 | 3 | 5 | Number of Under-Estimates |
| Re-Prediction Accuracy (%) | 100.0 | 93.6 | 93.6 | 96.8 | 100.0 | 100.0 | 93.6 | 93.6 | 87.1 | 83.9 | 71.0 | Re-Prediction Accuracy (%) |

* (No integer-feasible solution possible; Optimality not achieved)

Figure ~~14.~~ 26

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| Objective Function | Canonical Coefficient | Percent Variance Explained | Relative Rank |
|---|---|---|---|
| CERT | .9056 | 82.0 | 3 |
| CLAS | .8633 | 74.5 | 6 |
| BENE | .8729 | 76.2 | 4 |
| SUPL | .9077 | 82.4 | 2 |
| INST | .9339 | 87.2 | 1 |
| CONT | .8679 | 75.3 | 5 |
| TRAV | .8614 | 74.2 | 7 |
| CAPI | .8419 | 70.9 | 8 |
| PERC | .7870 | 61.9 | 9 |
| COMP | .7281 | 53.0 | 10. |

Thus it would seem, that a formalized objective of "maximizing" the expenditures associated with instructional materials in determining which programs to refund during a period of scant resourses, produced the highest correlation between the criterion matrix of 10 vectors and the proposed solution set vector constructed from the MAM analysis execution. Likewise, the maximization of 'budgetary composites' produced the lowest correlation, explaining only 53.0 percent of independent variance within the MAM solution vector.

The second 'phase' of measuring decisioning reliability exists in the accuracy of re-predicting solution set membership based upon the classification function coefficients generated via the discriminant analysis. The bottom portion of Figure 14 portrays these results for each of the 10 solution vectors formed by the varying criterion focus of the objective function. The results of re-classification for the selection tally vector are also displayed.

‹Figure 27› illustrates the similar results from applying discriminant function analyses to the solution vectors formed by minimization within a relaxed setting The three vectors for denoting criterion strength are easily distinguishable from the 7 successful (columns) optimizations. The re-classification portion of measuring decisioning reliability is also shown.

The computed canonical correlation coefficients for minimized-relaxed solutions:

| Objective Function | Canonical Coefficient | Percent Variance Explained | Relative Rank |
|---|---|---|---|
| CERT | .7721 | 59.6 | 6 |
| CLAS | -- | -- | -- |
| BENE | .7902 | 62.4 | 5 |
| SUPL | .8194 | 67.1 | 2 |
| INST | .7675 | 58.9 | 7 |
| CONT | .8000 | 64.0 | 3 |
| TRAV | .7928 | 62.9 | 4 |
| CAPI | -- | -- | -- |
| PERC | .9343 | 87.3 | 1 |
| COMP | -- | -- | -- |

demonstrated, that solution set formulated by minimizing the 'administrative perception' entries in determining a solution, to be the best fit with the overall criterion matrix; and the solution from minimizing 'instructional materials', the least 'best' fit.

Regarding the results of optimizing (both maximally and minimally) within the restricted environment, ‹Figure 28›

Summary of Criterion Vector Order-of-Entry, in Discriminating the Solution Set Vector for Each Cyclic MINIMIZATION within a RELAXED Region. (Note: Source of Discriminant Criterion Inclusion Vector; Discriminant Criterion Entry Vector; and Discriminant Weighting Summary Vector)

( VALUE OF OBJECTIVE FUNCTION DURING CYCLIC-OPTIMIZATION EVALUATIONS )

| Criterion Vector | CERT | CLAS | BENE | SUPL | INST | CONT | TRAV | CAPI | PERC | COMP | Selection Tally Vector | Discriminant Function # |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Certificated Salaries | 2<br>[2.37] | * | -- | 3<br>[1.41] | -- | 3<br>[1.22] | 3<br>[1.01] | * | -- | * | -- | -- |
| Classified Salaries | -- | * | 2<br>[2.16] | -- | 5<br>[1.00] | 4<br>[1.52] | -- | * | -- | * | -- | -- |
| Employee Benefits | -- | * | -- | -- | -- | 5<br>[1.00] | 4<br>[1.00] | * | -- | * | 2 | 6 |
| Supplies & Materials | 5<br>[1.00] | * | 5<br>[1.00] | 2<br>[1.97] | -- | -- | -- | * | 2<br>[1.37] | * | 6 | 4 |
| Instructional Materials | 4<br>[1.38] | * | -- | -- | -- | -- | -- | * | 4<br>[1.00] | * | -- | -- |
| Contractual Services | -- | * | -- | 5<br>[1.00] | 4<br>[1.27] | 2<br>[1.33] | -- | * | -- | * | 3 | 5 |
| Travel Expenditures | -- | * | 4<br>[1.45] | -- | -- | -- | -- | * | -- | * | 4 | 3 |
| Capital Outlay | 3<br>[1.99] | * | -- | -- | 3<br>[1.90] | -- | 2<br>[1.63] | * | 3<br>[1.17] | * | 5 | 2 |
| Administrative Perception | -- | * | 3<br>[1.34] | 4<br>[1.58] | 2<br>[2.74] | -- | -- | * | -- | * | -- | -- |
| Budgetary Composites | 1<br>[1.68] | * | 1<br>[2.95] | 1<br>[2.30] | 1<br>[2.08] | 1<br>[2.28] | 1<br>[2.24] | * | 1<br>[1.07] | * | 1 | 1 |
| Number of Mis-inclusions | 2 | * | 1 | 1 | 1 | 1 | 2 | * | -- | * | 3 | Number of Over-Estimates |
| Number of Mis-Exclusions | 1 | * | 3 | 1 | 2 | 1 | 1 | * | -- | * | 2 | Number of Under-Estimates |
| Re-Prediction Accuracy (%) | 90.3 | * | 87.1 | 93.6 | 90.3 | 93.6 | 90.3 | * | 100.0 | * | 83.9 | Re-Prediction Accuracy (%) |

* (No integer-feasible solution possible; Optimality not achieved)

Figure 15.

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Summary of Criterion Vector Order-of-Entry, in Discriminating the Two Distinct Solution Set Vectors Resulting from the Cyclic MAXIMIZATION and MINIMIZATION within a RESTRICTED Region. (Note: Source of Discriminant Criterion Inclusion Vector; Discriminant Criterion Entry Vector; and Discriminant Weighting Summary Vector)

| Criterion Vector | Solution Set #1 | Solution Set #2 |
|---|---|---|
| Certificated Salaries | 4<br>[1.05] | -- |
| Classified Salaries | 5<br>[1.00] | -- |
| Employee Benefits | -- | -- |
| Supplies & Materials | 2<br>[1.70] | -- |
| Instructional Materials | -- | 3<br>[1.00] |
| Contractual Services | -- | 2<br>[1.65] |
| Travel Expenditures | -- | -- |
| Capital Outlay | 3<br>[1.25] | -- |
| Administrative Perception | -- | -- |
| Budgetary Composites | 1<br>[2.11] | 1<br>[3.24] |
| Number of Mis-inclusions | 1 | -- |
| Number of Mis-exclusions | -- | 1 |
| Re-Prediction Accuracy (%) | 96.8 | 96.8 |

Figure 16.

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illustrates the discriminant function analysis framework. Similarly, the canonical coefficients were computed as:

| Solution Vector | Canonical Coefficient | Percent Variance Explained | Relative Rank |
|---|---|---|---|
| #1 | .8947 | 80.0 | 1 |
| #2 | .8628 | 74.4 | 2 |

## Summary of Findings

The use of discriminant functions in providing a useful post-hoc evaluation strategy for multiple alternatives decision-making has been studied within two separate real-world settings: the closure of schools; and the deallocation of program unit budgetary items. Two generalized issues of content and process were the main foci: *content*, in as much as there is a need to relate criteria used to the decisions made; and *process*, in order to verify the reliability of the decisioning procedures based upon the criteria utilized.

The author maintains, that two related "abilities" are necessary for prudent and trustworthy decision-making. The *first* ability refers to that knowledge which clarifies (1) which criteria 'effected' the decisions, and to what extent; and (2) to what degree did this 'effect' vary across the results of the cyclical optimizations. The *second* ability relates the need to study (1) the relationship between the 'optimizing vector' (objective function) and the results of a discriminant analysis; and (2) the relationship between the extent of feasibility region constraint (relaxed v. restricted) and the results of a discriminant analysis. To accomplish these ends, the multiple linear regression technique, discriminant functions analysis, is utilized to measure the topics of *criterion strength* and *decisioning reliability*.

The results of these discriminant analyses illustrate the superior efficacy found in relating multiple correlational strategies to discovering relationships between solution vectors and the criterion vectors (matrice) supporting those decisions. Three measures of criterion strength and two measures of decisioning reliability are illustrated for the reader -- all measures normally products of discriminant function(s) formulation.

It is a fundamental by-product of this study though all to important not to note, that the formation of "classification coefficients" within the discriminant process provides an excellent way of *projecting* expected impact from a newly collected set of data variables. By utilizing the linear combinations of this new data, 'expected correlative' decisions can be computed which maintain the same variance relationship as the decisions utilized originally in the initial discriminant analyses.

In summary, the use of discriminant functions in addressing the issues of criterion strength and decisioning reliability has been illustrated to hold great promise for the decision-maker, evaluator and otherwise problem-solver. Increased accountability, visibility and responsibility are the maximized ends.

# SUMMARY OF THE "MAM" FRAMEWORK AND "ROLBAK"

This study has sought to demonstrate the utility of the multiple alternative modeling formulation (MAM) in determining program units for continued funding during a fiscal crisis. Based upon an acceptance of criterion-referenced model for simulating future, probable decisioning alternatives, the MAM fiscal model, ROLBAK, evaluated various forms of data under different system goals (constraints), in order to observe the effect upon decision-making; that is, which program units to continue, and which to deallocate. Like the school closure and curriculum activity packaging models preceding it, this fiscal roll-back model will assist program administrators as they seek to continue program operation at an optimal level, though in a state of reduced funding.

## The Multiple-Alternatives Formulization

The multiple alternatives model (MAM) has been devised for the situations in which multiple solutions are required. School closures require more than one site be selected to remediate existing declining enrollment impacts and wastage of low per-capita expenditures. Curriculum activity packaging requires the best possible mix of instructional activities to match desired outcomes. And, funding crises require some select number of programs be designated for discontinuance.

The MAM concept models these evaluation complexes through the use of systems of linear inequalities and equalities. Each inequality (or equality) represents a specific objective predefined by the decision-maker; criterion referenced and labeled a constraint (to final solution selection). The system of inequalities and equalities relate each constraint objective to each of the decision alternatives being modeled (evaluated for ptoential inclusion with the final solution set). In addition, some one or several criterion vectors is (are) selected to act as the overall guide to decisional optimality, as the objective function.

## The ROLBAK Multiple Alternatives Model

The ROLBAK modeling structure studied within this paper, presents a MAM-adaptation to assist decision-makers when program areas must be 'cut'(i.e. deallocated) due to reduced funding. ROLBAK exists as a sane and rational alternative to the usual percentage-cut across-the-board; and allows the administrator to systematically criterion-reference such complex decisions.

Criterion-referenced constraints have been shown to potentially include budgets by object classification, surveyed perception of affected participants, and total budgetary composite control. In addition, the utility of varying criterion control (objective function) has been illustrated.

## Complex Approaches to Complex Issues

The authors maintain that issues involving many potential solutions are indeed too complex for the human mind to comprehend. Main-effects and interactive-effects modeling simulations provide a valid and reliable methodology for evaluating the MAM environment. Without such formulations, complex decision-making is little more than 1-part "experience" and 4-parts "blind luck" ( and often with less than successful results).

But the main areas of criticism will still prevail. First, that the need to quantify the criteria requires a greater committment to criterion-referencing than many decision-makers possess. Secondly, that high degrees of time, effort and sophistication are required of individuals who psosess little of the above. And finally, that the system requires optimally a computer; and human-based solutions should 'never' (?) be based upon computer analysis.

As social scientists and humans, simultaneously, we acknowledge these misgivings for what they are; and disagree amicably (sometimes).

## The Future of MAM Design

The matching of micro-computerized hardware and software to desired instructional objectives; the evaluation of item analysis techniques for designing computer-assisted survey techniques; and the consolidation of school districts -- are a relatively small but representative sampling of areas where this author is currently developing future MAM applications. Wherever a potential for multiple solutions exists, the multiple alternatives model will be there. Multiple alternatives modeling is not the wave of the future -- it is the available tool of today. Do it!!!

# PART IV

# FUTURE EXTENSIONS AND SUMMARY

# CHAPTER 10

# THE DISSEMINATION STAGE

## [ Extending the Multiple Alternatives Model to the Solution of Other Educational Problem Situations ]

## EDUCATIONAL MODELING AS THE NEW FRONTIER

As recent as 1978, speculation as to the positive potential of the multiple alternatives modeling framework for problem resolution in the field of education was decidedly in favor of the cynic. The idea of formulating a detailed mathematical model of a decisioning problem, wherein a number of plausible alternatives were to be evaluated across a set of competitive-interest criteria, was to say the least not exactly embraced by the leadership in education.

The opportunities for exploitation of the modeling framework were many and obvious; and educators were most reluctant to use a new technique for solving age-old problems -- especially in a climate where educators in general were not held in as high a professional regard as they might like or deserve. But the many problems which were consistent with a multiple-alternatives philosophy were not adequately resolvable utilizing the old techniques.

The prime example was the manner in which elementary schools were evaluated for potential closure, once the policy decision had been made to close schools as a means of resolving problems associated with declining elementary school enrollments. Many of the decisional strategies ranged from the superintendent chosing the sites based totally upon politically-motivated priorities, to the superintendent charging a committee of lay-persons to not only develop the criteria for determining potential closure, but also to analyze each site and submit a list of prioritized schools for school board approval.

This is not to say however, that there were no professional and/or ethical attempts to rationally deal with the school closure issue. But, these very spotty attempts were often twarted by efforts of other 'professionals' who would hide their own political motivations behind the vail of protecting a school for such reasons as historical preservation, the protection of the neighborhood-school concept, or the prediction of disasterous effect upon the child's psycho-social development if it became necessary for the student to have to transfer to a new school and make new friends. Unfortunately, many of these efforts over-rode the attempts to decrease surplus sites -- schools which have continued to drain district maintenance, energy and instructional budgets ever since.

In 1979, one district saw the high utility for such a complex modeling framework and its assistance to educational decisioning, and permitted the initial field studies and validation tests which were to prove the MAM approach to school closures as a very viable and reliable strategy (Wholeben, 1980a). Since that time, more applications of the multiple alternatives model and their utility for educational decision-making have become accepted by the educational leadership. As as been discussed previously in this text, the ROLBAK formulation (determining fiscal roll-backs during educational funding crises) and the MICROPIK formulation (evaluating computer-assisted instructional software and microcomputer hardware against curricular instructional objectives) have demonstrated further applicability for the MAM framework in the problems facing the educator today. Other work such as the development of the CAP formulation (curriculum activity packaging for instructional development; Wholeben, 1980b) have also illustrated the diverse utility of the multiple alternatives approach.

In this chapter, the reader will be introduced to several other MAM applications currently under study and experimentation within the educational community. This particular portion of the text will be necessarily general and non-detailed; and a more survey-orientation will be utilized in displaying various models.

For those of you who have survived this far, this will hopefully provide the needed encouragement to finish the remainder of the book.

The next section will focus mainly upon the wide-array of applications currently be developed. Then, three sections will focus more specifically upon three of these MAM formulations. Finally, the chapter will end with a few, chosen words on the barriers facing MAM utilization which may never be resolved.

# CURRENT DRAWING-BOARD DESIGNS

Someone very wise and knowledgable, and whom I am sure was very famous (although I am at a loss to remember a name for legal citation) -- nevertheless once remonstrated:

> "A professional is a person who having some unique and viable skill, carves out a problematic situation existent in society, and proceeds to demonstrate that this very individual skill is the preferred solution technique in all cases."

Having said the obvious with the likewise obvious intention, let us now proceed to explore several of the multiple-alternatives' applications currently under exploration and/or development.

## The "Good Times"

One can remember past years in education where the concern was not where the next dollar was to come from, or whether or not the school could stay in operation for the full term of the year -- but rather whether the school would be able to legitimately expend all of the fiscal resources made available to it. Many educational administrators (as well as many others) became very lax during these years of plenty. We forgot the value of hard work and merit, and the opportunities available through increased productivity and accountability.

Those days of harmony will reappear in the future; but they will not come (or remain) without a restructuring of the means by which educators currently conduct their business.

In anticipation of the return of the 'good old days' (?), several models are currently under design to assure that the prosperity which accompanies good times, does not likewise lead to the decay brought about by ample resources and technology.

One such model will assist the educational administrator in operationalizing the long-awaited philosophy of inservice training for the classroom teacher -- that everyone needs renewal sometime. The TCHRHELP formulation (identification of classroom teachers for remedial instruction) will assist this endeavor.

Another modeling formulation will aide the building administrator and curriculum departmental supervisor to arrive at a valid choice for hiring new classroom teachers in such a way, that not only the needs of the curricular area are satisfied, but that the demands of the school administrator for a balanced staff are likewise addressed. The TCHRPOOL model (employment interview pooling for teaching candidates) will meet these parallel needs.

A third use of the MAM framework seeks to provide new direction to the perrenial problems associated with collective bargaining and negotions. Whether unions see themselves as the protector of employee rights or the facilitator of the educational professionals' development and growth ... and whether adminstrators see themselves as management or the facilitator of the satisfaction of student needs and rights ... is not at issue in the model (although it should be of issue somewhere). The NEGOPAK formulation (bargaining package development and negotiations process planning) will seek to address the contents of a viable negotiable agreement -- what is demanded v. what is needed -- and what is possible or rational to expect as the end-product.

## The "Not-So-Good Times"

Of course, education is not under the constraints of what we might call good times; and currently faces some of the hardest decisions educators have ever had to make or comply with. Whether the United States Office of Education (or more recently, the Department of Education) was in fact a viable and managable unit is not a moot issue -- since it has gone the way of the Department of Energy under President Reagan's New Federalism. Interesting of course as a side-issue only (!) is the reaction of the public to regaining the lion's share of their independence -- panic!!

For years the common cry has been for less federal government interference within state educational affairs. That chance has now come -- but with the opportunity, comes also the mandate to conduct business-as-usual on our own volition. When "federal interference" stops, so also does "federal financial aide", a form of interference no one really seemed to mind. More seriously however, is the prospects for retention of the many educational reforms brought about solely because of federal mandated requirements. Can multiple alternatives modeling meet the test of these changing times?

Since the implementation of SCHCLO (the school closure model) and ROLBAK (the fiscal roll-back model), the obvious tendencies of further design and development has been to meet the demands of problematic situations -- declining enrollments and fiscal bases, respectively. Newer strategies (and in some cases, reformulations of older strategies) are currently under design for addressing the issues of maximized output demand with minimized input availability.

The DESEGCLO model (simulating feeder patterns for desegregation compliance under school closures) is an obvious reworking of the SCHCLO formulation, and its interface with a newer modeling strategy, the FEEDPAT framework (district transfer patterns for feeder schools).

Today's educational problems are not restricted to the larger school districts, however. Decreased fiscal resources have taken their toll upon the smaller school district as well -- especially in the case of the more rural centers. DISTMERG (attendance boundary redistricting and instructional program merger for consolidated school districts) is under development to assist the combining of several districts into an integral and functional whole.

Soon the lack of financial resources available to schools will become so pronounced, that wide-spread classroom teacher RIFs (reduction-in-force lay-offs) will necessitate a reverse in the current policy of LIFO (last in, first out) terminations. If in fact we believe that the teachers trained more recently in higher education institutions are better prepared for classroom teaching, and that many of our seasoned veterans are in fact 'dead-wood' -- the only reasonable course of action on termination decision will involve the evaluation of merit, performance, training and need as opposed to seniority only. The NOLIFO formulation (due-process policy analyses for district reduction-in-force) seeks to evaluate criteria indicative of preserving a quality instructional program in the face of personnel cut-back requirements.

Finally, the recent trend in medium-to-large school districts regarding the reconfiguration of their K-12 grade-level partitioning structures (e.g. from a K-6 to a K-5; and the resulting effect upon the remaining grade-level structures), has supported the design and experimental operationalization of the GRADRECON formulation.

Both DISTMERG and GRADRECON will be discussed in more detail in a later section of this chapter (as will MAINFIX (maintenance repair and scheduling; see next section).

### The "Assorted-Times"

There are of course multiple-alternative decisioning needs which are present without consideration of the 'polarity of the times'. We will mention a sampling of these circumstances, and illustrate some of the current MAM formulations in design and/or development stages for the resolution of their problematic orientation.

The necessity of building maintenance and repair, and the problems associated with identification, prioritization and the scheduling of remedial actions have long been a problem for the practicing administrator. There are always things needing fixing, but with differing priorities and varying materials availability, the identification and scheduling of these 'jobs' can be a time-consuming effort. As will be demonstrated in a later section, the use of the MAINFIX modeling formulation (maintenance repair and scheduling) can do a great deal in sorting not only the allocation of available monies according to required repairs, but also the individuals and materials involved as well as the priorities set by screening criteria.

Where the earlier design of the CAP model (curriculum activity packaging) sought only to evaluate multiple curricular objectives and relevant instructional activities for instructional packaging, the newly formulated CURRNET model (curriculum networking) will exploit the full curricular activities of the entire school (viz., mathematics, english, social studies, etc.).

For the district administrator who has everything, there is now the ITEMCHO formulation (itemized survey instrumentator) which designs community, student, staff (or whomever) survey instruments from a pool of potential items -- according to criterion-related needs, demands or circumstances.

And finally, for the state or federal officials in education who constantly complain of their inability to adequately make choices with regard to full program development (establishment of goals, and their delineation into viable action objectives), or with respect to the granting of support monies for special use (delineated budgeting development) -- there is now the GOALPAK (educational systems' planner and budgeting allocator) modeling framework.

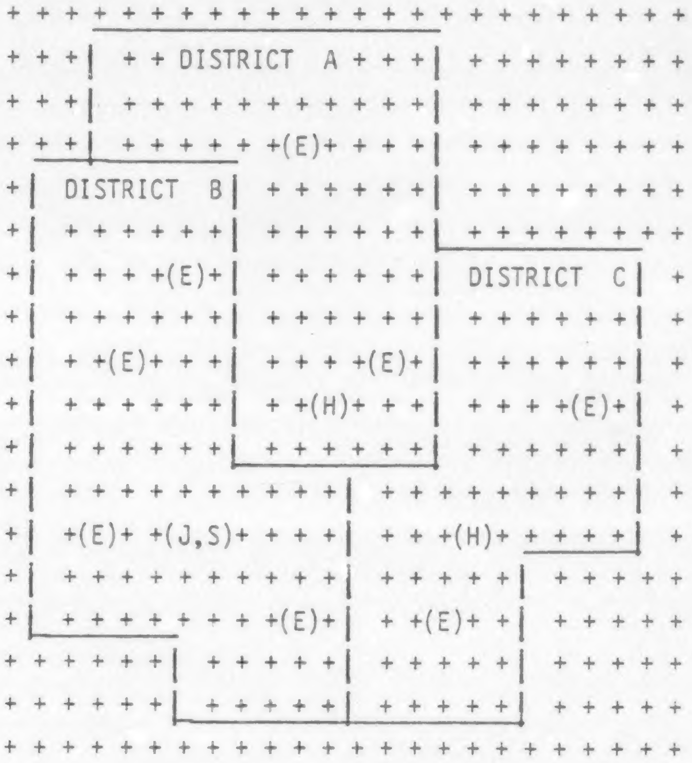
Three of these "drawing board" modeling formulations will now be described in some detail in order to enrich the reader's understanding of the MAM utility within the educational domain.

# DISTMERG - THE DISTRICT MERGER FORMULATION

In this section, the use of the multiple alternatives modeling formulation will be briefly described for its application to the goals found in the consolidation of multiple school districts.

## The Context

Consider the potential problems associated with an attempted consolidation of the three school districts (A,B,C) depicted below:



where, the codes E, J, S, and H represent elementary, junior high, senior high and high school (9-12), respectively.

The need for the forced-merger of two or more school districts into a consolidated district can often be linked to financial necessity. To maintain a quality instructional program, two small districts can often pool their resources, and establish the required fiscal support base. Sometimes, the fiscal relationship may be indirect, where a district finds itself without adequate building resources (for whatever reason: e.g. condemnation) and cannot float the necessary bond monies for construction. Of course, declining enrollments in both districts can be a highly motivating factor for merger, also.

The issues surrounding district consolidation will themselves encompass several diverse areas. One paramount issue will involve the decision as to whether the existing building sites will remain operational (highly unlikely), or whether some will be targeted for future closure. Potential closures notwithstanding, attendance areas will require redefinition of their boundaries; and thus children who had previously attended an elementary site within their original district, may now find themselves going to school in a closer, though different elementary site within a the previously neighboring district's boundaries.

From a programmatic point of view, a district merger can often require the re-centralization of program components within sites (centrally) accessible to the majority of children. This could mean the relocation of a special education program from one site to another -- and across once-existent inter-district boundaries. Finally, geographic as well as programmatic consolidation could very likely lead to required RIFs of instructional and support personnel.

## The Alternatives

The DISTMERG modeling formulation is approached via the land engineering technique called 'geocoding'. Geocoding simply means to divide the geographic area of the districts into like-area cells (called geocoded cells, obviously) by overlaying the area with a cartesian coordinate graph (shown above by the use of '+').

Each cell (x,y) coordinate represents a segment of an attendance area or residential partition which must ultimately be assigned as the principal responsibility of some school. While such criterion indicators as distance from each cell to each site, or number of potential enrollees via each cell is certainly calculatable -- it is likewise unnecesssary.

Each alternative is structured as the attendance cell which could reasonably be assigned to a particular school site. For the most part (except in relatively large districts), the main consideration will at least initially be with the elementary sites. Thus while (for example) cell [ 10,13 ] might be assigned to either of two elementary sites, it is unreasonable (and a waste of time) to consider the assignment of an attendance cell at one end of the map to be potentially assignable to a site at the other end.

The alternatives' structure for a very simple formulation may thus appear as follows:

| ELEMENTARY SITE #1 | | | | | ELEMENTARY SITE #2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1,2 | 1,3 | 1,4 | ... | 5,6 | 5,4 | 5,5 | 5,6 | ... | 7,3 |

where attendance cells [ 5,4; 5,5; 5,6 ] are potentially assignable to one or the other of the two imposed elementary sites.

For more complex formulations, the utility of the FEEDPAT (district transfer patterns for feeder schools) formulation would be required to solve the relationships of junior highs, etc. to the elementary sites be evaluated for attendance transferrees.

As will be mentioned below in the subsection concerning the formation of criterion constraints, the use of composite slack variables will be required to maintain some basic level of mandatory enrollment for a site, such that failure to achieve that attendance level will signal the site for potential closure.

## The Criterion Constraints

The DISTMERG formulation is not a simple model to construct, although its borrows heavily from its predecessor, the SCHCLO framework. Initially, the physically-oriented constraints will require quantification (distance of each cell to reasonable sites as measured by statute miles; time necessary in traversing the statute distance; actual enrollment density of each cell; architect's recommended capacity for each building; and so forth).

Attendance assigned to each building must be monitored in order to not violate capacity restrictions, while simultaneously each and every cell of the districts must be assigned to one and only one school. Required travel distance as summed across the cells will be minimized, while the assigned enrollment for each site will be maximized. The sum of a counting vector, where the value '1' is assigned for each unique and individual cell, must utimately equal the value of the number of total cells assignable.

More subjective criteria may be entered into the model in the form of parent's preference for one site over another; as well as the observed instructional-programmatic capacity of a building to support various desirable activities.

At the same time, a constraint maximizing the physical coverage of the district by building sites might be required. And the need to equalize minority population representation may likewise be a key ingredient of the consolidation-reassignment decision.

## GRADRECON - THE GRADE-LEVEL RECONFIGURATION FORMULATION

A complex modeling strategy which requires the use of slack variables is the GRADRECON formulation. GRADRECON is directed to evaluate the various grade-level patterns which might be of benefit to the restructuring of a school district. The major distinction between this model and many of the other designs is the flexibility surrounding sum-compilations of certain criterion vectors to denote K-5 v. K-6, or 6-8 v. 7-8 partitioned differences.

### The Alternatives

As displayed on the following page, the modeling structure of the multiple alternatives for the GRADRECON framework is developed by creating thirteen (13) storage locations for criterion data representative of each of the K-12 grade levels. The actual decisioning variables must then be constructed as composite slacks which will under execution contain the various sums of the variously partitioned K-12 grade levels.

For example, the [ K-5 ] and [ K-6 ] decision variables will contain poentially different sums based upon the fact that the K-5 unit will have grade-values K,1,...,5 summed within its storage location; whereas the K-6 unit will have grade-values K,1,...,6 summed within its storage location. Likewise for each of the identified slack storage composite.

The decision to choose a K-5 v. K-6 (or the simultaneous 6-8 v. 6-9 in the K-5 setting, as opposed to the 7-8 v. 7-9 in the K-6 setting) highlights the extreme complexity of the grade-reconfiguration decisioning strategy. At the same time however, this complexity also allows the extreme flexibility of the model to evaluate the 'more normal' combinations of grade levels which would likely exist within a single district.

A simple representation of this alternatives' model would exist as follows:

| | | | | | | | | | | | | | K | 6 | 6 | 9 | 10 | K | 7 | 7 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 5 | 8 | 9 | 12 | 12 | 6 | 8 | 9 | 12 | 12 | |
| v | v | v | v | v | v | | | | | | | | -1 | | | | | | | | | | =0 |
| | | | | | | v | v | v | | | | | | -1 | | | | | | | | | =0 |
| | | | | | | v | v | v | v | | | | | | -1 | | | | | | | | =0 |
| | | | | | | | | | v | v | v | v | | | | -1 | | | | | | | =0 |
| | | | | | | | | | | v | v | v | | | | | -1 | | | | | | =0 |
| | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | | =3 |
| | | | | | | | | | | | | | | 1 | 1 | | | | | | | | =1 |
| | | | | | | | | | | | | | | | | 1 | 1 | | | | | | =1 |
| v | v | v | v | v | v | | | | | | | | | | | | | -1 | | | | | =0 |
| | | | | | | v | v | v | | | | | | | | | | | -1 | | | | =0 |
| | | | | | | v | v | v | v | | | | | | | | | | | -1 | | | =0 |
| | | | | | | | | | v | v | v | v | | | | | | | | | -1 | | =0 |
| | | | | | | | | | | v | v | v | | | | | | | | | | -1 | =0 |
| | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | =3 |
| | | | | | | | | | | | | | | | | | | | 1 | 1 | | | =1 |
| | | | | | | | | | | | | | | | | | | | | | 1 | 1 | =1 |
| | | | | | | | | | | | | | 1 | | | | | 1 | | | | | =1 |

where 'v' represents the various criterion values (non-differentiated) associated with the required constraints of the decision.

## The Criterion Constraints

Certain field representations have found, that criteria which represent the 'contribution' of a particular grade level to the overall configuration best allows the model its necessary flexibility. Because of the structure of the model in requiring the decision variables to be the slacks, the physical size of the formulation itself can become quite large -- and yet remain a scant matrix because of its (see above) numerous zero submatrices.

Although not shown (the author does have some compassion), additional criterion values could be modeled directly within the slack portion of the formulation -- demonstrating particular contributions of one formulation (e.g. a K-5, 6-8, 9-12 as opposed to a K-5, 6-9, 10-12 formulation but within the same K-5 setting) over another.

## MAINFIX - THE MAINTENANCE-REPAIR SCHEDULING FORMULATION

A final representation of another multiple alternatives model within the educational sector remains the use of mathematical modeling structures to decision maintenance priorities, and the resulting scheduling of these prioritized repair needs.

### The Alternatives

The construction of MAINFIX is a unique contribution of the MAM framework, since the model is normally executed at least two separate times. The initial execution is defined the identification run, wherein the various maintenance alternatives are evaluated, and those fitting within the allocated budget are selected.

The second execution is the scheduling run -- that is, with the decisioned alternatives as now representative of a reduced set of alternatives, each alternative being sub-delineated into three subcategories: early term, middle term and late term, as concerning the time-of-term for each maintenance unit's repair time-scheduling priority.

### The Criterion Constraints

The MAINFIX formulation with the exceptance of its required two-phase execution, is a basic criterion formulation of a full matrix. Criterion indicators common to maintenance costs, number of personnel required, degree of priority, availability of the necessary repair materials and/or equipment are all represented.

The secondary execution -- where the time for repair is decisioned as opposed to the actual identification of the intended repair -- is somewhat more complex, though not as compelling for instant insanity as either the DISTMERG or GRADRECON model(s). Criterion measures of need, demand and subjective priority are input in order to select a scheduling frame of either term-1, term-2 or term-3 for each and every identified priority. Care must be taken of course, to insure that one and only one scheduling term is decisioned for each identified alternative.

## UNRESOLVABLE BARRIERS -- THE EDUCATIONAL DILEMMA

A final commentary on the utility of the MAM framework must be offerred in order to conclude this chapter on a realistic, though somewhat pessimistic and downbeat, note.

A cursory reading of the aforegoing material concerning current developmental and experimental models for multiple alternatives decision-making might lead one to believe that salvation for the educational administrator is but around the technological corner. Nothing (it is sad for me to say) could be further from the truth.

Although it is obvious that some knowledge of the modeling concept is prerequisite to successfully implementing the MAM orientation, it is not as obvious as to the potential barriers existent within the modeling formulation itself -- that is, the identification of alternatives, and the subsequent definition and measurement of appropriate criterion constraints. That most institutions of higher education which credential or otherwise train school administrators today do not offer courses in the application of quantitative modeling to decision-making -- beyond the usual elementary statistics course required for the masters degree -- signals the unfortunate regard many administrative trainers have for the use of numbers in evaluation.

Note the wariness on the part of many educators towards a highly structured approach to evaluative decisioning (and in a sense, accountability), and the reader has a very realistic view of the usual acceptance of a mathematical modeling framework for evaluating and determining final decisions.

And if training and experience do not provide sufficient obstacles to the use of modeling for evaluating alternatives, the reader has only to recall (on one hand of five fingers) the number of times over the past year, where decisions were made based upon solely political considerations in lieu of the actual enforcement of the data cited as the basis of the decisions so administered.

Now for the upbeat and positive side ...

Current litigations and court rulings point to a renewed interest on the part of communities for informed decision-making. More and more, teachers are questioning the actual criterion base upon which decisions are made -- and furthermore are examining the decisions made against the criterion indicators held as indicative of those decisions. For their part, the emerging educational administrator is slowly recognizing the very influential role of computers as a medium for new forms of evaluation and decision-making. In effect, the future of education is not tomorrow's innovation, but rather the recognized use of that innovation as a means of making education more accountable and more available to external validation by its critics.

# CHAPTER 11

# THE CONSOLIDATION STAGE

[ Related Topics and Perspective ]

# COMPUTERIZATION AND AVAILABLE SOFTWARE

A common question posed to the author from the field as to the implementation of the MAM framework, revolves around the obvious requirement for computer hardware and packaged software in order to utilize the mathematical formulation for evaluation and decisioning.

During the past five years, various modeling software packages have been utilized to differing degrees of satisfaction and ease. Invariably, a particular software package will be hardware-bound, and thus what might have existed on a UNIVAC 1110 will (may) not be available on a CDC CYBER 170-750 or IBM 370. Although these machines are considered macro-mainframes, several equally good packages are available on what have come to be known as superminiframes or mini-computers (e.g. VAX 11/780 or HP3000).

In this section, we will be concerned primarily with the software packages the author has utilized, although mention will obviously be made as to the type of machine housing the particular package.

## Macro-Computerized Software

The Madison Academic Computing Center (MACC) at the University of Wisconsin at Madison utilizes a UNIVAC 1110 macro mainframe; and supports a wide-array of mathematical programming software (of which integer programming routines are but a few) for use as mathematical modeling routines for the School of Engineering, School of Business, and the Department of Computer Science.

One such software package, known as IPMIXD, performs a standard solution generation complex by way of a FORTRAN-based subroutine. The MAM problem is modeled within a FORTRAN-written program, and the IPMIXD package called as a standard subroutine reference. The output ranges from a few pages to boxes ... and the analyst must be extremely careful when assigning initial parameters. IPMIXD is fairly powerful, and provides readable output for the novice.

The University of Washington (in Seattle) utilizes a relatively new CDC (Control Data Corporation) CYBER 170-750 number-cruncher within its Academic Computer Center (ACC). The predominate integer-programming package is the standard MPOS (Multi Purpose Optimization System) package distributed through the Vogelback Computing Center at Northwestern University in Evanston, Illinois.

Unlike IPMIXD, the MPOS integer routine (called BBMIP) is a key-word oriented selection of commands -- not requiring the modeler to first prepare a standard FORTRAN (or other compiler-based language) program. Such a program has obvious ease for the non-programmer. MPOS provides for external datafile access, and therefore can be considered extremely flexible, as well as powerful.

While both MPOS and IPMIXD are both batch-processing oriented packages, another software package available on the University of Washington macro-system is the interactive package, EZLP. This mathematical programming routine was developed at the Georgia Institute of Technology and also allows indirect datafile access from an external source. Coupled with the ability to be accessed interactively from a terminal, and executed on-line -- EZLP provides immediate feedback and solution formulations for relatively medium-sized problems.

## Mini-Computerized Software

Developed by Dr. Linus Schrage of the University of Chicago, the interactive package LINDO (Linear Discrete Optimizer) is available on such mini-computers as the Digital Equipment Corporation's VAX 11/780 and PDP machines. While somewhat easier to use as opposed to the EZLP interactive package, LINDO does have a major shortcoming -- external datafile elements are non-accessible to the programming routine. Therefore, all data must be entered in the form of the algebraic inequality, for each and every criterion constraint. However, LINDO is by far, the easiest for the novice-student to learn, and implement. Output is good; and will be as annotated for the user as initially input.

## Micro-Computerized Software

To the current knowledge of this author, there exists no integer programming MAM routines for use in such micro-computers as APPLE or TRS-30. However, plans are currently underway by the author to develop a moderate-sized routine written in BASIC for the TRS-80 TRSDOS BASIC and APPLESOFT BASIC compilers.

# PERSPECTIVES AND IMPLICATIONS

One of the hardest parts of writing a fairly lengthy manuscript is developing a reasonably meaningful last chapter. Obviously, the more important points concerning context, design, implementation and interpretation have been dealt with in previous chapters. At the same time, good authors should somehow bade their readership farewell ... so ...

This text has been postulated on the belief, that the role of the educational leader in the years to come will require greater involvement within problem analysis and resolution from a more quantitative perspective. Although educators and other social scientists have for decades espoused, that not everything is measureable -- there are nonetheless ample opportunities in which to develop quantitative assessment strategies for evaluation and decisioning within the educational environment. The mathematical modeling methodology developed within this text is certainly a firm example of the power which the manager could display in dealing with the complex issues of today.

While at the University of Washington, I have managed to develop a doctoral seminar in which practicing administrators have been instructed in the use of the multiple alternatives modeling methodology -- a practice I will be able to continue with the University of Texas at El Paso. A copy of the course perspectus has been included for the reader's perusal within the appendix of this text.

Yet with the eagerness and enthusiasm displayed by the students within this seminar, there has also been the willing disregard for the model from some school districts in the area who could have availed themselves of such a simulative design for determining school closures, or ear-marking program terminations under fiscal recession. And then again, other school districts have embraced the design with at the least, a need to understand whether or not their criterion indicators will in fact discriminate between potential solution alternatives.

As educators become more accountable, and as school boards and community groups demand more visibility and responsibility from their appointed educational leaders -- the role of models like MAA will take on new importance and like. It is ridiculous to assume, that the computer or its associated software will in effect make the decision modeled. But, it is likewise ignorant to assume, that the use of a quantitative analysis framework is worthless since it has not been widely accepted or utilized.

Like computer literacy and high school proficiency examinations, mathematical programming and multiple alternatives modeling will come into its own -- not because it was desired or even liked -- but because it was finally recognized as unavoidably necessary.

# APPENDICES

A: COURSE OUTLINE FOR MAA INSTRUCTION

B: COURSE SYLLABUS FOR MAA INSTRUCTION

C: OUTLINE FOR MAA FIELD PROJECT STUDY

# APPENDIX A: COURSE OUTLINE FOR MAA INSTRUCTION

## SPECIAL PROBLEMS IN EDUCATIONAL ADMINISTRATION

## "Evaluation Modeling for Educational Decision-Making"

* * *

This course will examine the role of *mathematical modeling* techniques, and their importance within the realm of educational evaluation and decision-making. Class presentations will be sequential; and will deal with such issues as areas of technique application, general design constructs of the "Multiple Alternatives Model" as portraying the execution of "Multiple Alternatives Analysis", specific building steps in formulating an individual model, computer-oriented techniques useful during the design and analysis stages, and required pre- and post-analysis statistical procedures for assessing content validity and process reliability.

Although course *pre-requisites* are not currently permitted for selected entry into this seminar, the student is advised of the following assumptions on the part of the professor: that each seminar member have successfully accomplished at least two courses in statistics, have at least a rudimentary understanding of the formation and utilization of simultaneous linear equations and inequalities from linear algebra, and have had some prior experience with writing and executing SPSS statistical programs on the CYBER 170-750 (main campus computing mainframe).

Because of the sequential nature of the material to be presented within the class sessions, attendance at each session is mandatory, and without exception except in cases of emergency. This rather unusual requirement is demanded due to the complexity and technical difficulty associated with the course content. It has been found over the past three years, that students missing any amount of (or portion thereof) the sessions have been unable to complete course requirements. EdAdm 537 is an advanced seminar; and since the majority of the attending students are pursuing doctoral study, such attendance perogative should be assumed a priori.

Since this seminar is truly 'field-applications' oriented, individual readings will be confined to those contained within the course texts, and those additional library references which individual students will have to survey based upon the topic and direction of their particular course project. Individual work on the defined field project is required; and therefore, no group projects will be allowed. No examinations or tests are planned at the conclusion of this seminar. Full basis for the final course grade depends upon the results of the individual field application, and the appropriateness of the final project report. Exceptions to or substitutions for the project and report will not be allowed.

The final report associated with the field application is expected to be a fully-edited, clean manuscript of approximately 20-25 pages, typed, 1½-spaced, and following the rules of some acceptable thesis preparation guide (NOTE: the APA PUBLICATION MANUAL is strongly suggested as a useful and relatively inexpensive investment, and is available at the campus bookstore). All tables a/o figures must be fully readable, labelled, and set-off on separate pages from the general text of the manuscript. Manuscripts which would not be considered acceptable for publication as a journal article, will not be accepted as fulfilling the course completion requirements. A general topical format for your consideration, but only as an example, is:

ABSTRACT (100 words or less)
INTRODUCTION TO THE PROBLEM
DISCUSSION OF THE TECHNIQUE
MODEL DESIGN AND DEVELOPMENT
DATA MEASUREMENT AND FORMULATION
EXECUTION AND RESULTS
VALIDITY AND RELIABILITY TESTS
DISCUSSION AND SUMMARY
IMPLICATIONS

Modifications to the above outline are acceptable; but the student is cautioned to remember, that some of the major criteria to be utilized in judging the final report will be those of completeness, thoroughness and understanding.

The subject or focus of the actual field investigation is at the discretion of the student, with approval from the professor. The field problem to be modeled must however be of such a nature, that it demonstrates the qualities of a true 'multiple alternatives' situation, and that the application of a quantitative evaluation and decision-making model to the problem's remediation will result in a useful documentation of content and process information for the educational field practitioner. Due to the time restrictions placed upon an academic quarter seminar, there will exist some negotiable room between 'what is defined' as the bases for a full-implementation of the specific decisioning (sic) model, and 'what is sufficient' for empirical denotation of the validity and reliability issues involved in the resolution of the defined problem.

‹EdAdm 537› exists as one of the more intense seminars in the 530-series, and demands an extreme, almost dogmatic attentiveness and participativeness on the part of the student. This particular seminar has also been found to be a most useful sequence in the development of skills for evaluating and resolving many of the more complex problems facing the emerging educational administrator today. Computer systems are but tools; and quantitative analysis techniques for resolving complex issues are but skills; you are the catalyst which can make them work for the optimization of educational performance and progress.

## [Section 01] INTRODUCTION TO MODELING & APPLICATIONS

1. The Multiple Alternatives Setting
2. Policy v. Action Alternatives Modeling
3. Main v. Interactive Effects Modeling
4. Single v. Multiple Entry Solutions
5. Linear Inequalities and System Impact
6. Maximization/Minimization for Optimality

## [Section 02] TECHNICAL COMPONENTS OF THE MAM FRAMEWORK

1. Measurement Scaling and Data Generation
2. Criterion Definition and Referencing
3. Development of Decisional Alternatives
4. Criterion Comparison Vectors
5. RHS-Limits and the Conditional Vector
6. The Constraint Matrix
7. The Objective Function

## [Section 03] CONSTRAINT MATRICE AND CONDITIONAL VECTORS

1. The General System Impact Constraint
2. The Specific Alternative Impact Constraint
3. Modeling the Four Measurement Scales
4. Search for Initial Integer Feasibility
5. Relaxed v. Restricted RHS-Influence
6. Modeling Maximization v. Minimization Bounds

## [Section 04] OBJECTIVE FUNCTIONS AND CYCLIC OPTIMIZATION

1. Utility of a Cyclic Optimization Procedure
2. Development of the 'Tracking Matrix'
3. Structure of the System Database
4. Post-Hoc Assessment of Results Per Cycle

## [Section 05] DEFINITION AND DEVELOPMENT OF ALTERNATIVES

1. Mutual-Exclusiveness for Independence
2. Collective-Exhaustiveness for Total Control
3. Delineation Paradigm for Alternatives
4. Single-Entry and Multiple-Entry Definition
5. The Hierarchical, Multiple-Entry Situation
6. Tautological Comparison and Control

## [Section 06] DESIGN AND CONSTRUCTION OF THE DATABASE

1. Review of NOS Command Procedures
2. Introduction to the UEDIT System Editor
3. Computing Initial Statistics Using MINITAB
4. Transposing Column-Vectors to Row-Vectors
5. Building MAM-Databases Utilizing MINITAB
6. Modifying the Database with the UEDIT Editor

## [Section 07] DESIGN AND CONSTRUCTION OF ANALYSIS PROGRAMS

1. Introduction to MPOS Integer Programming
2. UEDITing the MPOS Executable Package
3. SUBMITing, QGETing and ROUTEing Results
4. Normal Techniques for Initial Feasibility
5. Comparing Restricted v. Relaxed Solutions
6. Common Mistakes with the MPOS Package
7. Verifying MPOS Analyses and Findings

## [Section 08] PRE-ANALYSIS STATISTICS FOR MODELING CONTROL

1. CORRELATION for Criterion Independence
2. ONEWAY ANOVA for Undesirable Criterion Bias
3. FACTOR ANALYSIS for Criterion Efficiency

## [Section 09] POST-HOC STATISTICS FOR VALIDITY & RELIABILITY

1. ANOVA and the Optimality Weighting Matrix
2. DISCRIMINANT FUNCTIONS and Predictability
3. UEDITing the Database for SPSS Analyses

## [Section 10] FORMULATION FOR STEPWISE SOLUTION STRATEGIES

1. Dichotomizing the Selection Tally Vector
2. Restructuring the RHS-values
3. Restructuring the Database via UEDIT Editor
4. Approaching the Final Solution Set as Limit

## [Section 11] INTERACTIVE MULTIPLE ALTERNATIVES MODELING

1. The EZLP Package
2. The LINDO Package

## APPENDIX B: COURSE SYLLABUS FOR MAA INSTRUCTION

<General Topic> <Specific Reference> <Instructional Objectives>

### MULTIPLE ALTERNATIVES CONTEXT

1: school closures
2: curriculum activity packaging
3: pre-employment teacher interview pooling
4: microcomputer hardware/software matching
5: budgetary roll-backs
6: school district consolidations
7: attendance boundary redistricting
8: elementary school grade-level reconfiguation
9: feeder-pattern control
10: survey questionnaire item-analysis and selection

### GENERATING MULTIPLE ALTERNATIVES

1: delineation of objectives' framework
2: 'brain-storming' framework
3: 'random-components' framework

### DEFINING CRITERIA FOR MAM ANALYSIS

1: generic orientation
(effectiveness,efficiency,satisfaction,expenditure)
2: species orientation
(intent,method,value,means)
3: measure orientation
(physical,transformational,definitional,synthetic)

### DEVELOPING CRITERIA FOR DATA COLLECTION

1: documentation reviews
2: survey collection

## SCALING CRITERIA FOR DATA MEASUREMENT

1: common scaling techniques
2: counting techniques
3: weighting techniques
4: probabilistic-measurement techniques

## FORMULATING LINEAR INEQUALITIES

1: vector summations
2: slack storage units
3: tautological decisioning vectors

## COMPUTING THE CONDITIONAL VECTOR

1: raw-score summation technique
2: t-normal generalized effect technique
3: differential impact technique
(mean w/ standard deviation)
4: special case of the 'scant' conflict matrix

## PREPARING THE OBJECTIVE FUNCTION

## CONSTRUCTING THE DATABASE

1: access to the CYBER 170/750
2: use of the MINITAB package
3: T-Normal transformations
4: matrix transposition procedures
5: conflict matrix generation

## STATISTICAL ROUTINES TO PRE-ANALYZE CRITERIA

1: Product-Moment Correlation
2: Non-parametric Correlation
3: Oneway Analysis of Variance
4: Factor Analysis

## MPOS(BBMIP) ROUTINE TO ANALYZE MAM PROBLEM

1: access to the CYBER 170/750

    2: Northwestern University MPOS Routines
    3: use of the BBMIP integer programming routine

STATISTICAL ROUTINES TO POST-ANALYZE SOLUTION(S)

    1: Oneway Analysis of Variance
    2: Discriminant Function Analysis
    3: Multivariate Regression

CYCLIC OPTIMIZATION AND THE TRACKING MATRIX

    1: dichotomy-scaled selection techniques
    2: observation-scaled selection techniques

STEPWISE SOLUTION(S) AND RHS-UPDATING

MODEL RELIABILITY AND SOLUTION VALIDITY

# APPENDIX C: PROPOSAL OUTLINE FOR MAA FIELD STUDY PROJECT

## CONSTRUCTING THE EDADM 508 PROJECT PAPER

‹A Guide to Content and Sequence›

| Item | Delineation of Contents |
|---|---|
| ABSTRACT OF PROPOSAL | 1. 350 words or less, in 3 paragraphs<br>2. 1st paragraph = statement of mission<br>3. 2nd paragraph = statement of method<br>4. 3rd paragraph = statement of results |
| TITLE PAGE | 1. title of project, with short 1-sentence description of project<br>2. authorship credit, with credential<br>3. statement of funding credit<br>4. statement of disclaimer |
| TABLE OF CONTENTS | 1. all major topics, and main subtopics, by page reference<br>2. appendice reference by page number<br>3. list of attachments |
| LIST OF FIGURES/TABLES | 1. full title of figure and/or table with page reference |
| INTRODUCTION TO PROPOSAL | 1. general introduction to the proposed program and/or project |
| ASSESSMENT OF NEED(S) | 1. design of the assessment, with statement of 'significant others' participation |

| | |
|---|---|
| | 2. rationale for data collected, analysis interpretation(s), and decisions drawn<br>3. specific reference to the constructive 'interrogative adverbs' of WHO, WHERE, WHEN, HOW, WHY, and WHAT<br>4. discussion of multiple alternative strategies toward problem resolution, and the (suggested) strategy to reconcile direction |
| STATEMENT OF PROBLEM | 1. 1-page discussion of the perceived problem; more of a narrative summary of the "assessment of need(s)" section |
| STATEMENT OF MISSION | 1. 1-page statement of the intended direction of the remediation tactics to be developed within the remainder of the proposal |
| DELINEATION / OBJECTIVES | 1. utilize the format of:<br>phase.goal.objective.activity.task<br>2. structure this section in outline form:<br>01 Statement of Phase<br>01.01 Statement of Goal<br>01.01.01 Statement of Objective<br>01.01.01.01 Statement of Activity<br>01.01.01.01.01 Statement of Task |
| NARRATIVE DESCRIPTION | 1. narrative explanation of project<br>2. review of supporting rationale for decisions made during design and development<br>3. explanation of time and other resource allocations |

4. explanation of responsibility assignments
5. summary via GANNT Chart

FORMATIVE EVALUATION

1. explanation of framework suggested to conduct 'program improvement' evaluation
2. definition of criteria to be measured
3. discussion of measurement schemes for data collection
4. denotation of major 'milestones' where significant departures from expected schedule will require a restructuring of the proposed program

SUMMATIVE EVALUATION

1. explanation of framework suggested to conduct 'performance output' evaluation
2. definition of criteria to be measured
3. discussion of measurement schemes for data collection
4. suggested summary reporting procedures for the assessment results to each of:
    a. effectiveness (intent)
    b. efficiency (method)
    c. satisfaction (value)
    d. expenditure (means)

REPORTING OF RESULTS

1. explanation of the structure for the final document to be submitted at the conclusion of the program's implementation
2. introduction of 'sample' reporting figures, tables or graphs

APPENDICE

1. copy of goals/objectives flowchart
2. copy of activities/tasks network
3. 'summary of activities' pages from the

CPM computer analysis

4. dayfile page from the computer run

ATTACHMENTS

1. any supporting documentation, figures or other materials, which are germane to presentation of the proposal but not necessarily a formal part of the program

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